Block-Constant Modulus Signaling

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Abstract

The predominant limitation on performance in wireless communication schemes results from multipath fading in the transmitted signal. This interference complicates data transmission by introducing time-varying phase and amplitude distortion. As a result, most wireless communication systems have had to sacrifice the performance by utilizing less efficient amplitude-invariant schemes in lieu of higher data rate modulation schemes (e.g. PSK instead of QAM).

However, many wireless channels are slow-varying in nature. This makes it possible to approximate the fading characteristics of such channels as stationary during short blocks of time. This approximation is utilized in the construction of two block modulation schemes based on the principle of a per-block constant modulus. Such schemes are resistant to amplitude distortion resulting from slow-fading and the use of block coding techniques permits more efficient, higher data-rate wireless communication systems. The first constant-modulus block scheme is based on a combinatorial adaptation of Phase-Shift Keying with multiple ring sizes. The second is a modified application of the Shell Mapping algorithm first introduced in the V.34 modem. Preliminary analysis and simulations of these two methods through Additive White Gaussian Noise and Rayleigh Fading channels demonstrate potential for both schemes in the form of reduced symbol error rate and/or increased bit-rate. Furthermore, in some cases these schemes are very competitive with the performance of traditional Phase Shift Keying and Quadrature Amplitude Modulation schemes.

Block-Constant Modulus Signaling

Why :

- Multipath fading distorts amplitude in wireless channel
- High data rate modulation (QAM) requires knowledge of channel amplitude.
- Currently used amplitude-invariant modulation (PSK) does not scale efficiently to high data rates.
- Many channels are slow fading: amplitude and phase distortion are static over duration of block. Hence block encoding.
- Channel characteristics from block to block vary. Hence 'amplitude' or modulus of block held constant to mimic amplitude invariance of PSK. This leads to simplified decoding.

Approach :

- Signaling block of N complex samples viewed as a point in $2N$-dimensional signal space. Constant modulus requires all points to exist on surface of hypersphere.
- Develop a method to efficiently produce, index, and if possible assign bitstrings to points on a $2N$-dimensional hypersphere.
- Simulate performance of multidimensional constellation through White Gaussian Noise and Flat Rayleigh Fading channels.

Ring-Swapping

In this first method a block consisting of multiple PSK rings is used to combinatorially encode data. By fixing the number of rings of each size in the block the overall modulus can be held constant. Also by properly Gray-coding the PSK rings and the bitstrings are effectively assigned to points in the multidimensional constellation.

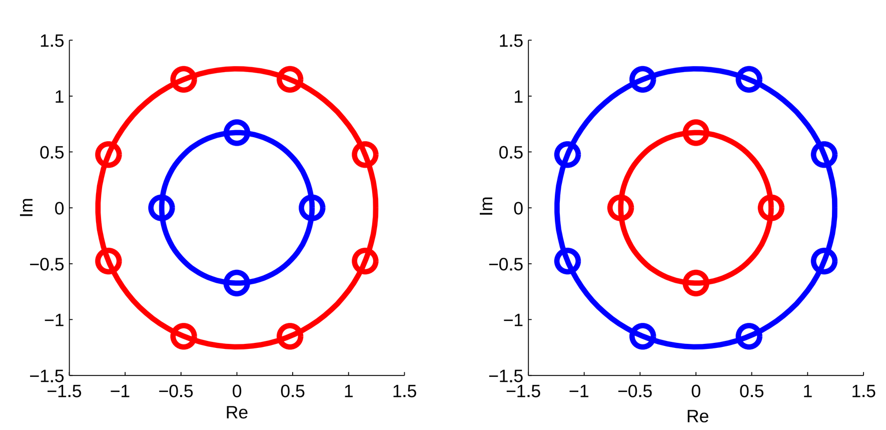

Figure 1. An example of the possible pairings with a two-complex-sample Ring Swapping constellation using 4-PSK and 8-PSK rings. Colors denote combinatory ring-size order selection. In this configuration there are 2 bits from the 4-PSK ring, 3 bits from the 8-PSK and 1 bit for the ordering of rings in the block for an effective 3 bits per complex sample. This is the same as 8-PSK but at slightly reduced signal power.

Ring Swapping Analysis

Table 1. Ring Swapping Combinations and Complex Sample Bit Rate

Combination	Maximum Bits per Sample	Simulated Bits per Sample
4-8	3.000	3.0
4-8-8	3.195	3.0
4-4-8-8	3.146	3.0
4-4-8-8-8	3.264	3.2

Note: a '4-8' configuration indicates a two sample block with a combination of one 4-PSK ring and one 8-PSK ring

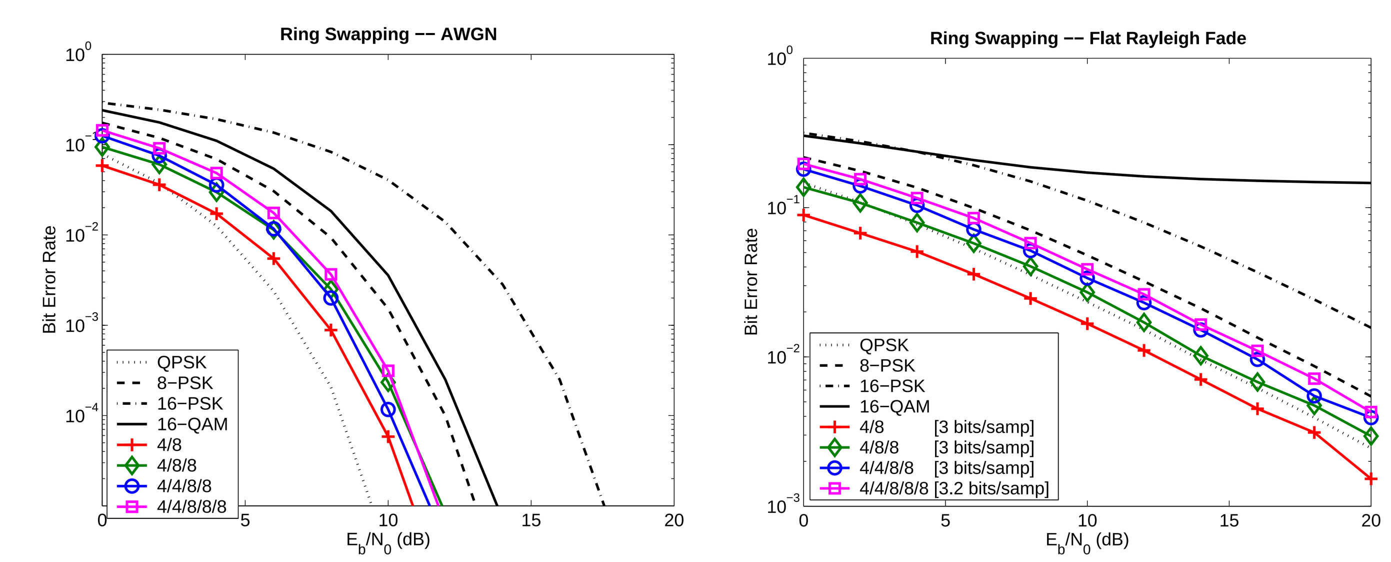

Figure 2. AWGN and Flat Rayeleigh Fading channel simulations of Gray-coded Ring Swapping Method

By combinatorially encoding data into the order of varying ring sizes it is possible to improve performance of the wireless system considerably. However, in actuality the increase in data rate asymptotes at one bit per sample as the size of the block increases so this method will not drastically improve data rate.

Shell-Mapping

The shell mapping algorithm is an efficient way of indexing points within a multidimensional solid based on the 'cost' of the point (typically based on a specified norm). It debuted commercially as a feature in the ITU-T Recommendation V.34, where it was used to shape the multidimensional constellation to decrease the average power. Constraints on the peak-to-average power ratio (PAR) and the constellation expansion ratio (CER) were also easily incorporated into the shell mapping method. (6)(3)(4)(7)

However the shell-mapping algorithm conveniently also groups points with the same cost value. It does this by using a 1-dimension generating function to calculate the number of possible permuatations resulting in an N-dimensional vector with an associated cost. Since we wish to create a hypersphere by using the L2 norm as the cost function it is possible to create a suitable multidimensional constellation. A generalized combinatorial approach and from (5) is used in the simulations here.

Factors in Adapted Shell-Mapped Constellation

- The set of 1-D costs is determines possible values along each axis. Since the energy along each axis is the cost, a set of (1,4,9) would yield possible magnitudes of (1,2,3) along each axis in signal space.
- The overall energy (modulus) of the block must be the sum of a combination of the 1-D costs.
- Some block moduli are associated with more permuatations of the 1-D costs. These will create more dense signal constellations that can transmit more data.
- The shell mapping algorithm produces only absolute value of points along each axis so another bit can be encoded for the sign of each point.

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Shell-Mapping Analysis

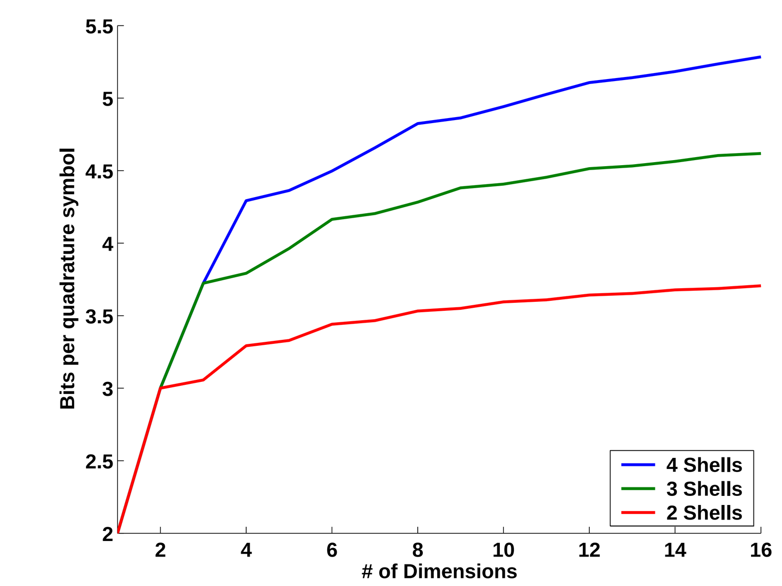

Figure 3. Bit rate vs. block size for adapted Shell-Mapping with 2, 3, and 4 1-D shells

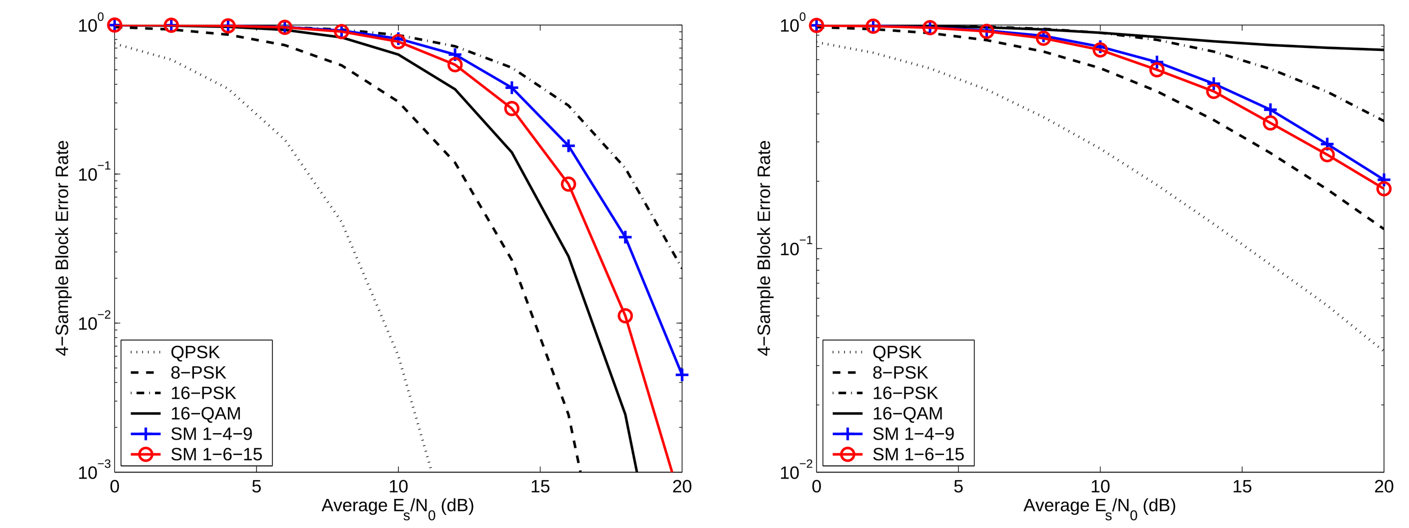

Figure 4. AWGN and Flat Rayleigh Fading channel simulations of Shell-Mapping method. '1-4-9' and '1-6-15' denote the values for the 1-D shells. Note: symbol error rate is for 4 sample blocks of each scheme

The simulations show here can transmit at a maximum of 4.25 bits per sample based on the number of points in the constellation. However shell mapping is more scalable than the previous discussed method. Also, since shell-mapping produces a non-power of two set of points there is also some redundancy which may be utilized in error correction or detection. These results slow that the shell-mapping algorithm may be a competitive in a block-constant modulus scheme with the development of a method of coding data to the points.

Conclusions

These results clearly confirm the viability and prospect of the block-constant modulus apprach. We have demonstrated two instances where by using the block-constant modulus approach we can either maintain or improve performance despite increasing data rate. It is important to note that there may be other possible methods of arranging points on the surface of the hypersphere to create a constellation. Also, for both of these methods whatever coding or bitstring assignment was done was sub-optimal. These may be areas of future study.

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