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Using Spread Spectrum with Narrow Band Channels

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Spread Spectrum for Wireless Channels

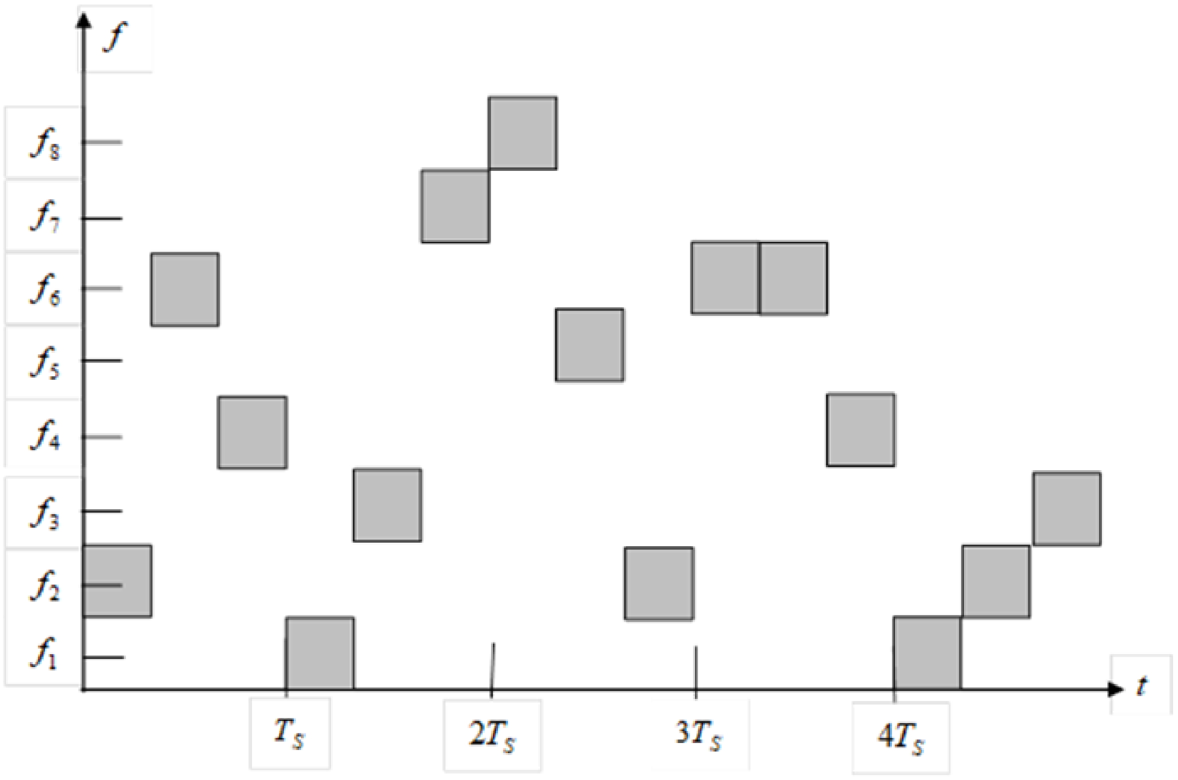
- Spread spectrum has the advantages of:
  - Reducing detectability
  - Mitigating various forms of fading
  - Enhancing resilience to external and self-interference
- Raytheon’s typical wireless radios use a combination of spread spectrum and frequency hopping to achieve resilience against eavesdropping and combat jamming
- Spread spectrum is avoided for narrowband channels (10s of Hz) because the room (frequency band) for spreading is limited

Although needed, spread spectrum is avoided with narrow band channels

Reviews

The use of spread spectrum with frequency hopping

- Mixing frequency hopping and spread spectrum offers resilience against eavesdroppers and jammers.
- It is hard to synchronize with the frequency sub-band at any given moment.
- Even if there is sync, spread spectrum makes the signal appear as background noise.

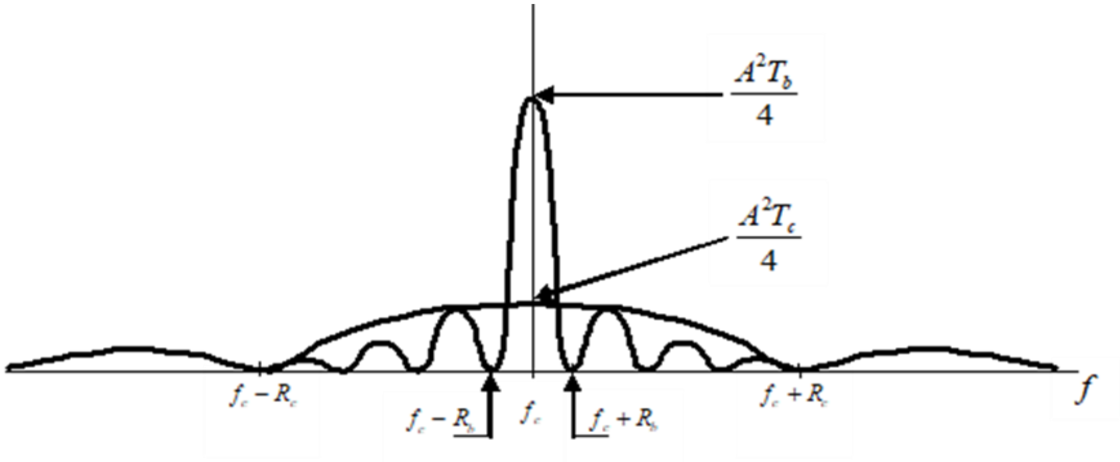


With a narrowband channel, there is no room for frequency hopping and spread spectrum

Reviews

Spread spectrum hides the RF signal

- The spread signal is like noise
- The existence of harmonics is a telltale of a modulated symbol.
- Increasing the spreading factor means decreasing the ratio of $\frac{T_c}{T_b}$.
- We should strive to at least line the main (center) harmonic of the spread signal within the sub-band frequency range, such that spreading makes the signal as close to low-power noise as possible.



Frequency domain Spread v non-spread signal

Maximizing spreading with the narrowband channel is needed

Review

Orthogonal Spread Codes

- Engineers strive to create orthogonal codes
- This minimizes self-interference
  - If we transmit 2 signals at the same time using the same frequency sub-band, the two signals would not interfere with each other because the spreading codes are orthogonal to each other
  - Each is background noise to the other
- The Hadamard matrix is a form of maximizing the number of orthogonal spreading codes for a given spreading factor

What to do with a narrow band channel?

- For a channel with a bandwidth in the range of 10s of Hertz, the spreading factor we can use is very small and can be meaningless
- There is no room for frequency hopping
- Alternatively, if we can increase the number of orthogonal spreading codes, we can ***hop (cycle) through spreading codes*** for evasion

If we can maximize the number of orthogonal spreading codes in the narrow band channel, we can compensate for the lack of combined frequency hopping and spread spectrum by cycling through spreading codes

The Challenge

- Maximize spread spectrum with narrowband channels
  - It will allow us to leverage the advantages of spread spectrum
    - ➢ Signal hiding
    - ➢ Mitigate self and external interference
  - It will allow us to hop between spreading codes for evasion
- Some solutions generate a single polynomial or a limited number of known polynomials, given the channel's parameters:
  - For example, Kasami generator polynomial can produce a small set of Kasami sequences (primitive polynomial of degree n=6)
  - The polynomials are Known -- the signal can be discovered
  - No room for mitigating self and external interference
  - Not enough entries for evasion

We need to maximize the spreading capability beyond the known limits

The Solution

- We are seeking a matrix-based, not a polynomial-based solution
- Maximize spreading ***beyond known channel bandwidth limitations***
- A Hadamard matrix with a large set of orthogonal spreading codes for a long spreading factor
- Although this matrix may not be considered suitable for the narrow-band channel, within this matrix, we can find subsets of orthogonal codes that can survive the channel's limitations. Consider:
  - The matrix can map to a rate per 2 seconds, a rate per 4 seconds, and so on. Some applications can transmit a signal every n seconds where $n > 1$
  - We have room for correcting ***lossy compression***. The large matrix allows the receiver's cross-correlation to mitigate some chip loss due to channel effects

We want to go beyond the channel rate in bits/sec and beyond known max spreading by considering lossy compression

The Experimental Solution

- We used MATLAB to generate a large Hadamard matrix
  - We spread the signal beyond the channel's per-second bitrate limitations
- We experimented with the entries of this matrix. We were able to:
  - Identify a subset of spreading codes that can't survive the channel even when the channel doesn't introduce noise (noiseless channel).
    - ❖ This subset is discarded since it can't survive the channel's ***lossy compression***
  - Assign to the rest of the entries in the matrix a rank based on each entry's ability to survive the channel's bandwidth limitation and a given signal-to-noise ratio (SNR)
  - This means that if we know the channel's SNR, the transmitter and receiver can switch (hop) between all the orthogonal spreading codes that can survive the channel's SNR

The main aspects of the solution are:

(1) The consideration of lossy compression,

(2) The consideration of signal harmonics, and

(3) Invoking Set Theory (dynamic sets)

The Sought Solution

Just as Hadamard matrices are known and can be found in MATLAB for given parameters, the solution should be implementable in MATLAB, where it defines:

- Hadamard matrices with large spreading factors
  - ❖ Maximize spreading, to increase the pool of usable spread codes
- The channel's bandwidth (Harmonics and lossy compression)
- A given SNR range
  - ❖ SNR is dynamic, making the available pool of spreading codes dynamic
- Other parameters, such as fading

That solution will identify the suitable subset from the large Hadamard matrix and how the available pool of spreading code varies with SNR.

Analogy

- Shannon proved that there is no point in joint source and channel coding or modulation and channel coding, provided that optimum solutions are used at each stage
  - Practical solutions proved otherwise
  - The ideal optimization at each stage is achievable by joining the stages
  - There are gains from joint source and channel coding and joint modulation and coding
- Bandwidth limitation shouldn't prevent us from maximizing spreading
- What we seek is a joint solution. We join spreading with:
  - The message's time length. The message rate per n seconds, where $n > 1$
  - The channel bandwidth (impacts lossy compression and harmonics)
  - The channel's SNR
  - Other channel parameters, such as fading

This is merely and analogy

Hadamard Transformation

- The solution may lie with the Hadamard transformation
- Hadamard transformation is related to the Fourier Transformation
- Lower harmonics in the Hadamard transformation are lower harmonics in the Fourier Transformation
- Hadamard Transformation is already amended by:
  - **Walsh Ordering:** Rows are reordered by increasing frequency
  - **Dyadic/Paley Ordering:** Rows are ordered based on the binary Gray code

Aspect 1: Account for lossy compression in the channel:

- Mapping the Walsh ordering to a channel bandwidth creates a **set** of usable codes for our channel
- That **set** size can increase, considering how the receiver's cross-correlation recovers additional entries
- This leads to using a larger Hadamard matrix than was originally thought for the given channel

We can refer to **Aspect 1** as joint lossy compression, Hadamard coding, and channel coding (inner error control coding)

Hadamard Matrix

8x8 Hadamard Matrix

$$H = \begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 \\ +1 & +1 & +1 & +1 & -1 & -1 & -1 & -1 \\ +1 & -1 & +1 & -1 & -1 & +1 & -1 & +1 \\ +1 & +1 & -1 & -1 & -1 & -1 & +1 & +1 \\ +1 & -1 & -1 & +1 & -1 & +1 & +1 & -1 \end{bmatrix}$$

No Harmonics

Low Harmonics

Distance of 4

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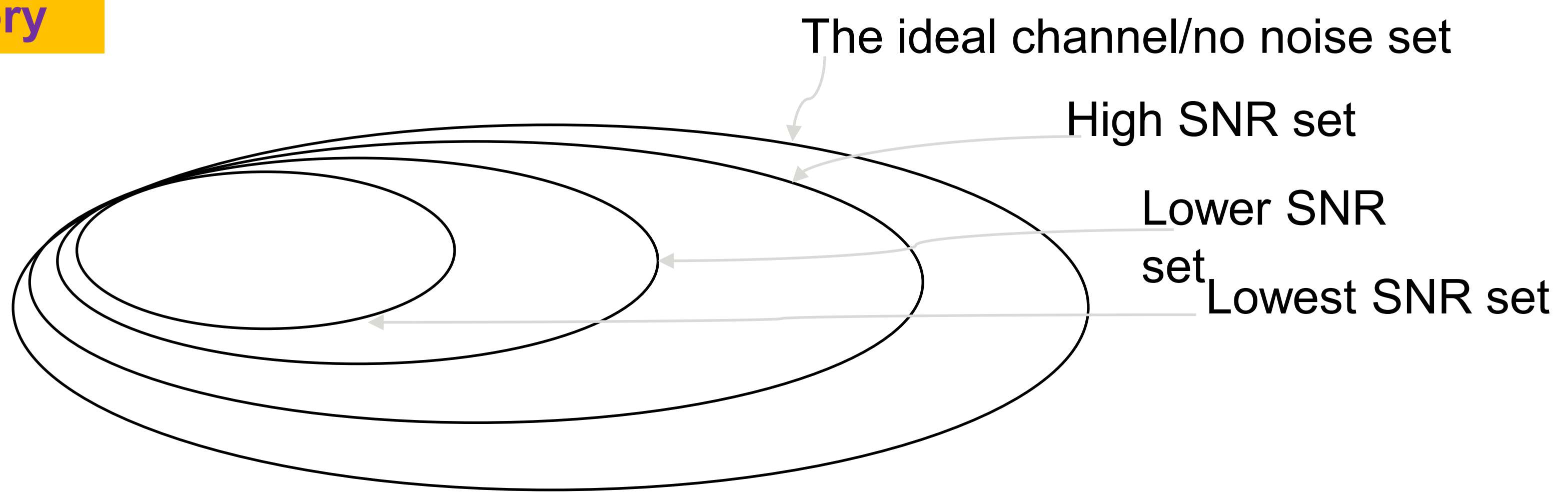
What is in the literature, and what is missing

In the literature	Need complement
Mapping a set of low harmonics entries to a narrow band channel	Consider the impact of lossy compression and cross-correlation on additional entries
Finding sets with distance limits	Relating the distance/Gray code to lossy compression recovery and SNR

Aspect 2: Invoke Set Theory

We can refer to **Aspect 2** as joint Set Theory and maximizing the Hadamard matrix size



Summary

- There is a need to maximize spread spectrum with narrow band channels
- The road to this maximization is to join:
  - Lossy compression of the channel
  - Hadamard transformation with respect to channel harmonics
  - Replace channel coding (inner error control coding) with increased chip rate
  - Invoke Set Theory
- It is possible to assume digital binary phase shift keying modulation
  - This will not impact the ability to create the desired joint solution
- We desire the solution to be:
  - Dynamic sets so that channel feedback can result in changes to the usable set
  - implemented in MATLAB