In the Name of Allah

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Telecommunication Systems Project Report

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Index Modulation[1]

Index modulation refers to a family of modulation techniques that rely on activating certain resources/block structures for embedding information[2]. These resources/block structures can be physical, such as antennas, sub-carriers[3], time slots[4], frequency carriers, etc. Though index modulation techniques have gained academic attention in the past decade, large technology companies have only recently realized their undeniable potential.

Some advantages of index modulation include:

- Inherent flexibility with adjustable number of available entities[5] for active transmission.
- Ability to transfer stored energy from inactive entities to active ones for achieving improved error performance.
- Increase in spectral efficiency without increasing hardware complexity due to the utilization of new dimensions for transmitting digital information.

Joint Radar and Communication Systems[6]

The sharing of frequency bands between radar and communication systems has garnered considerable attention as it can prevent the wasteful permanent allocation of spectrum resources and consequently enhance efficiency. Additionally, there is a growing demand for radar and communication systems that share hardware platforms and frequency bands, as this not only reduces spectrum usage but also benefits from full cooperation between both functionalities in terms of sensing and signaling operations. However, the success of spectrum and hardware sharing between radar and communication systems heavily relies on high-quality joint radar and communication designs.

[1] index modulation
[2] information embedding
[3] subcarrier
[4] time slot
[5] entities
[6] joint radar and communication system

System Model

The system introduced in the paper utilizes the characteristics of Frequency Modulated Continuous Wave (FMCW) as an index for communication of information. Moreover, the primary application of this system is radar sensing.

The carrier frequency (f_c), bandwidth (B), and indices are utilized for modulating the transmitted information. We can represent the transmitted signal with the following equation:

$$x(t) = e^{j2\pi(\frac{1}{2}\alpha t^2+\beta t+\gamma)}$$

where $t \in [0, T_c]$ and α, β, and γ are chirp parameters.

Furthermore, for the carrier frequency and bandwidth, we have:

$$f_{(min)} \leq f_{(min)} + k\Delta_f \leq f_{(max)}, \ B_{(min)} \leq B_{(min)} + l\Delta_B \leq B_{(max)}$$

Information is encoded in frequency and bandwidth. If L denotes the number of possible values for bandwidth and M denotes the number of possible values for frequency, then:

$$log_2(ML) = \text{encoded bits}$$

Considering the given bandwidth range, 400 MHz $\leq B \leq$ 700 MHz, we can transmit 7 bits in bandwidth. Also, considering the given frequency range, -100 MHz $\leq f \leq$ 100 MHz, we can transmit 6 bits in frequency.

To process the reflected chirp, it is mixed with a sample of the transmitted chirp. This operation is referred to as "de-ramp," resulting in a beat signal, whose frequency represents the distance from the target from which the signal is reflected. Therefore, the distance from the target can be obtained by spectral analysis of the beat signal. The general detection process involves creating a library of all possible chirps. After receiving and segmenting, each chirp is normalized, and by performing FFT, it is compared with all the FFTs we have. Finally, the FFT with the minimum distance is identified as the output.

The system parameters are provided below. Additionally, 0.1μ seconds are considered as guard time, which reduces ISI and helps us in signal separation.
$f_c = 62.64$ GHz and $f_s = 2 \times 10^9$ samples/sec and $T_c = 15.2$ microseconds

Receiver

The proposed method for extracting information from received chirps and decoding them is based on computing the Fourier transform of the signal and then utilizing the Maximum Likelihood (ML) estimator. In this method, after receiving the message signal, we transform it into different frequency domains and then compare the normalized Fourier transform distance with the normalized Fourier transform of all standard signals. The minimum distance of the Fourier transforms reveals the desired chirp for us. Clearly, this method is quite resistant to noise. However, constructing a receiver capable of computing the Fourier transform of the signal for information extraction and comparing it with standard signals is very costly.

To alleviate the time required for computing the Fourier transform of the signal, we can employ a time-domain estimator. In this case, with a reduction in the signal's frequency bandwidth, the computation time in the time domain significantly increases and is not suitable for signals limited in the frequency domain.

Another recommended method, which is easier compared to computing the Fourier transform, is the use of Short-Time Fourier Transform (STFT) of the signal. As we know, for signal encoding, the initial frequency bandwidth and frequency components are important to us. Therefore, having these two components is sufficient for detecting the transmitted message. This estimator is faster compared to previous estimators and consumes less time and information volume, consequently providing us with a cheaper receiver. The only issue with this type of estimator is its lack of resistance to noise compared to the previous method, which is more sensitive to noise. In such cases, if the signal is noisy and the initial frequency and bandwidth cannot be distinguished with the normal sampling rate, a larger window for STFT must be considered, resulting in a longer time required for information extraction.

Considering greedy algorithms, we can find the sparsest possible solution within the loop with a threshold. These types of algorithms are much faster, and their only drawback is adding a slight error at each stage, which ultimately does not affect the final result. To determine the threshold, one can run the algorithm several times and calculate the optimal value based on the error.

One-Bit Transfer

0.1 Up Chirp/Down Chirp

To send a single bit using frequency analysis, changes in frequency behavior can be tracked. One of these behaviors can be modeled using the increase or decrease in received chirp frequency, such that increasing or decreasing frequency can be considered as a communicated message.

This behavior can be interpreted as a binary signal, where frequency decrease represents bit 0 and frequency increase represents bit 1.

0.1.1 Down Chirp

$\theta = -\alpha t + \beta \longrightarrow x(t) = \exp\{2j\pi \left(-\frac{\alpha}{2}t^2 + \beta t + \gamma\right)\}$

0.1.2 Up Chirp

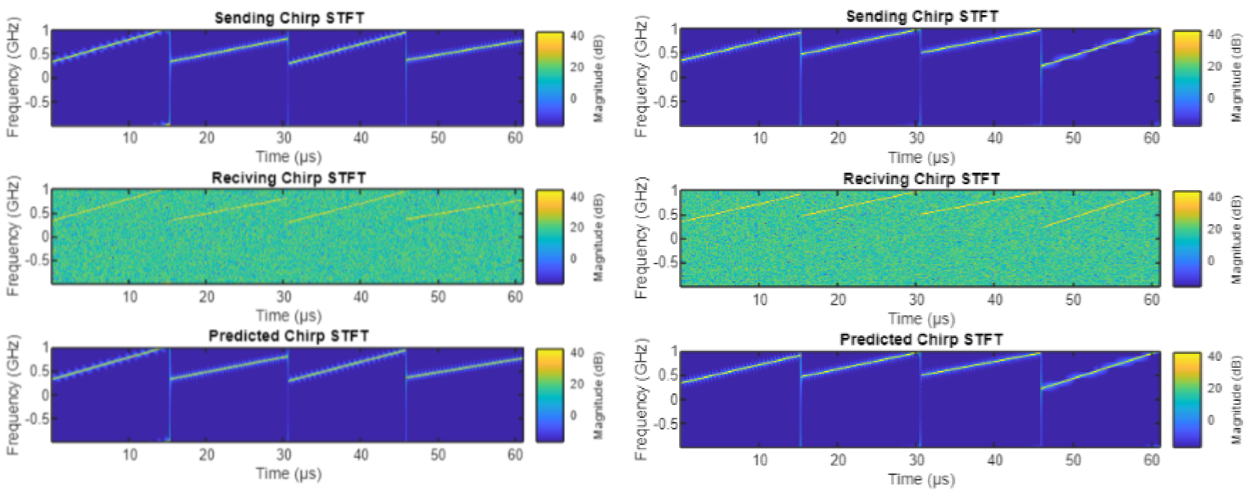
$\theta = \alpha t + \beta \longrightarrow x(t) = \exp\{2j\pi \left(\frac{\alpha}{2}t^2 + \beta t + \gamma\right)\}$

0.2 On-off keying

This type of message communication, which is the simplest form of communication, can be considered as a type of ASK (Amplitude Shift Keying), where sending a message with non-zero magnitude is represented by bit 1, and sending a message with zero magnitude, having no frequency component for analysis, is represented by bit 0.

0.3 Results

An example of the transmitted, received, and processed signal:


Sending Chirp STFT
Reciving Chirp STFT
Predicted Chirp STFT
Frequency (GHz)
Time (μs)
Magnitude (dB)
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