A Study on AFDM: Principles and ISAC Applications

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A. Motivation of Affine Frequency-Division Multiplexing (AFDM)

The orthogonal frequency division multiplexing (OFDM) waveform has been instrumental in the success of 4G and 5G networks, particularly under the assumption of slow-moving transceivers and stationery, linear time-invariant channels. However, the advent of next generation 6G networks necessitates a shift in this paradigm. Future networks are expected to support seamless and reliable information exchange in highly dynamic environments, including high-speed rail, vehicle to everything (V2X) communication, high altitude platform station (HAPS), and low Earth orbit satellite communication. These scenarios share a common physical characteristic: high relative velocities between the transmitter and receiver. This high-speed mobility inevitably introduces a significant doppler effect. Consequently, the primary operational channel for 6G will no longer be the conventional linear time-invariant channel, but rather a more generalized doubly dispersive channel (DDC).

Under a DDC environment, the OFDM waveform exhibits a critical limitation: the doppler spread causes a loss of sub-carrier orthogonality, leading to a breakdown of signal integrity and the generation of inter-carrier interference (ICI). This inherent weakness highlights the growing need for a new waveform robust to DDC conditions. In this context, this paper introduces and explores the potential of a promising technology known as affine frequency-division multiplexing (AFDM).

B. Basics of AFDM

AFDM is a multi-carrier modulation scheme that transmits symbols using chirp sub-carriers as its basis functions. In contrast to conventional OFDM, where the frequency of the basis function is constant, the AFDM basis function's frequency increases linearly with time. This unique characteristic is particularly well-suited for channels that experience a significant doppler effect, and signals of this nature are referred to as chirp signals. In an OFDM system, a doppler shift imposes a frequency offset on the fixed carrier frequency, f, which destroys the orthogonality between sub-carriers and leads to ICI. AFDM, however, addresses this challenge effectively. The instantaneous frequency of an AFDM signal can be expressed as a linear function of time, such as 2kt+f, where k is the chirp rate. When a doppler-induced frequency offset, v(t), is applied to this signal, the received signal's instantaneous frequency becomes 2kt+(f+v(t)). Crucially, this offset merely shifts the signal's center frequency without altering the chirp rate, k. As a result, the received signal retains its fundamental chirp structure, maintaining robustness against doppler effects.

C. Itegrated Sensing and Communication (ISAC) using AFDM

AFDM can also be usefully applied to integrated sensing and communication (ISAC) technology. While AFDM is fundamentally a communication technology, its inherent chirp structure allows it to simultaneously function as a radar signal. This allows the chirp signal to be used not only for communication but also for sensing, identifying, and measuring the surrounding environment. Consequently, the dual roles of 6G communication and the sensing capabilities of traditional radar systems can be integrated and handled through AFDM.

References

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