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Source: Cohere Technologies, AT&T, CMCC, Deutsche Telekom, Telefonica, Telstra

Title: Overview of OTFS Waveform for Next Generation RAT

Agenda item: 8.1.1

Document for: Discussion and Decision

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1. Introduction

The 5G air interface and associated modulation have to support a number of diverse requirements and usage scenarios as detailed in [1] and [2]. In particular, this contribution addresses requirements driven by the eMBB usage scenario and associated high speed deployment scenarios, for which current solutions are not well suited, and proposes a new modulation and reference signal scheme ideally suited to these requirements.

Of particular relevance to this contribution are the eMBB deployment scenarios in [2] involving high speed traffic, namely 6.1.5 High Speed and 6.1.9 Highway Scenario. These two scenarios include proposed vehicle speeds of 500 km/h and up to 300 km/h respectively. In addition, we believe that high speed V2X scenarios will ultimately include high throughput use cases (e.g., video to and from automobiles). It is well known that under higher Doppler conditions (for example, the ETU-300 channel model), channel estimation performance and associated OFDM modulation performance break down. This performance degradation is exacerbated with higher order MIMO due to the strong correlation between performance and accurate channel estimation. In addition, capacity increasing techniques such as cooperative multipoint and massive MIMO require accurate channel estimation and the support for a large number of reference signals under all Doppler conditions in order to approach their promised performance gains.

All of the deployment scenarios associated with eMBB are characterized by large numbers of antenna elements. Leveraging these antenna elements in a massive MIMO architecture requires a highly efficient reference signal multiplexing mechanism otherwise the bandwidth overhead required for the large number of antenna ports will overwhelm the available data bandwidth.

In this contribution, and the associated detailed contribution from Cohere [4], we propose a new modulation scheme and a new reference signal architecture, which both provide significant performance improvements over existing methods in high Doppler and high-order MIMO systems. These techniques also greatly enhance reference signal multiplexing efficiency relative to existing solutions. The diverse use cases and requirements of 5G may also drive the need for a flexible or software defined air interface allowing efficient configuration of physical layer building blocks like frame structure, duplex, multiple access, MIMO, coding and modulation etc., according to KPI requirements in each specific 5G use case, as described, for example, in [5]. The waveform proposal in this contribution would fit well into such an architecture, since it is based on an underlying multicarrier structure.

2. Discussion

In this paper we introduce a new 2D modulation technique called OTFS (Orthogonal Time Frequency & Space) that transforms information carried in the Delay-Doppler coordinate system to the familiar time-frequency domain utilized by traditional modulation schemes such as OFDM, CDMA and TDMA. OTFS converts the fading, time-varying wireless channel into a non-fading, time-independent interaction with the transmitted symbols, revealing the underlying geometry of the wireless channel. In this new formulation, all QAM symbols experience the same channel and all Delay-Doppler diversity branches of the channel are coherently combined. Because channel state acquisition is done in the time independent Delay-Doppler domain, accurate channel estimation is achieved, even in the presence of high-mobility. In addition, because antenna port reference signals are carried in the Delay-Doppler domain they can be packed very efficiently, allowing large numbers of reference signals to be flexibly multiplexed based on the delay and Doppler spread characteristics of the individual channels.

OTFS modulation is explained in more detail in [4]. Here we present a high level overview of the modulation and reference signal architecture.

2.1 OTFS Modulation Overview

OTFS works in the Delay-Doppler coordinate system using a set of basis functions orthogonal to both time and frequency shifts. Both data and reference signals or pilots are carried in this coordinate system. The Delay-Doppler domain mirrors the geometry of the wireless channel, which changes far more slowly than the phase changes experienced in the rapidly varying time-frequency domain. OTFS symbols experience the full diversity of the channel over time and frequency, trading latency for performance in high Doppler scenarios.

Figure **1** illustrates the modulation and demodulation steps. The transmit information symbols (QAM symbols) are placed on a lattice or grid in the 2 dimensional Delay-Doppler domain and transformed to the time-frequency domain through a two dimensional Symplectic Fourier Transform. Through this transform, each QAM symbol is spread throughout the Time-Frequency plane (i.e., across the selected signal bandwidth and symbol time) utilizing a different basis function. As a result, all symbols of the same power have the same SNR and experience exactly the same channel. The implication is that, given the appropriate frequency and time observation window, there is no frequency or time selective fading of QAM symbols. The transform converts the multiplicative action of the channel into a 2D convolutive interaction with the transmitted QAM symbols. OTFS allows for the same OFDM shaping benefits seen in various forms of filtered OFDM. OTFS extracts the full diversity of the channel at the modulation level, allowing the FEC layer to operate on a signal with uniform Gaussian noise pattern, regardless of the particular channel structure.. OTFS enables a flexible trade-off of observation time or latency for increased performance in high Doppler scenarios. For non latency-sensitive traffic, such as video in a high-speed scenario, this is a reasonable trade-off. For more latency-sensitive scenarios, OTFS allows scaling of the observation to a single OFDM symbol.

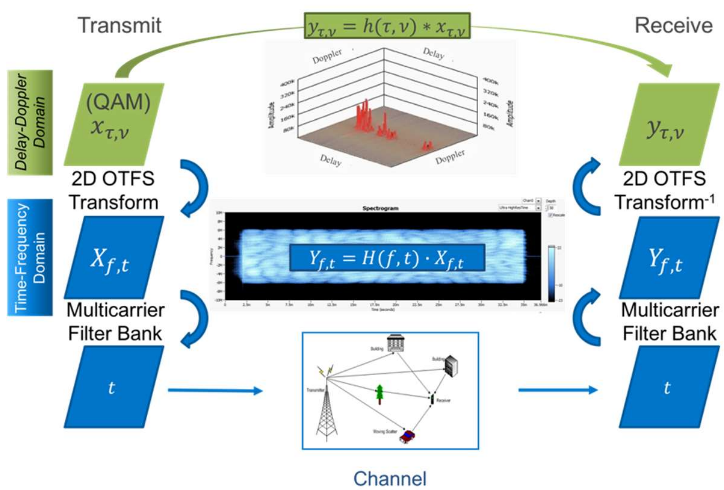

Figure 1: OTFS Processing

2.2 OTFS Reference Signal Overview

In addition to the modulation symbols, OTFS reference signals or pilots are carried in the delay-Doppler domain as impulses to probe the channel. Each pilot has a space reserved around it to account for the maximum delay and Doppler spread of the channel. Like the information symbols, the pilots experience the same time and frequency diversity of the channel over the full observation bandwidth and time and the interaction with the channel results in a 2D convolution of the delay-Doppler impulse response with the pilot, as shown in Figure 2. By extracting the received pilot this impulse response of the channel is directly obtained.

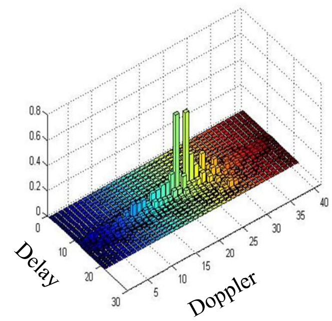

Figure 2: Delay-Doppler Impulse Response

OTFS reference signals (aka pilots) are defined in a separate delay Doppler plane and mapped to a properly selected grid points in the time frequency domain that don't overlap with the OTFS information carrying grid points. This allows flexibility and dense multiplexing of antenna port reference signals and allows for accurate prediction of the channel even in high Doppler environments (valuable for multiuser-MIMO precoding). OTFS reference signals are compatible with both OTFS and OFDM modulations, equally achieving dense, efficient and robust multiplexing of large numbers of reference signals. This has important implications for MU-MIMO applications which require a large number of antenna ports to be efficiently multiplexed in various Doppler scenarios. It is shown, as an example in [4] and **Error! Reference source not found.**, that for a 5 μs delay spread and $100Hz$ Doppler spread channel, that 88 reference signals can be multiplexed in 7% of the available bandwidth for an overhead per antenna port of just 0.08%. In addition, further efficiency can be obtained with knowledge of channel conditions for different users or groups of users by flexibly assigning different pilot spacing in the delay-Doppler domain for different users.

Simulation and performance results for OTFS modulation and reference signal packing and channel estimation are shown in [4].

3. Conclusions And Recommendations

OTFS is a new 2D air interface paradigm with important spectral efficiency advantages in high order MIMO and high Doppler scenarios, reference signal efficiency and channel estimation and prediction. All reference signals and QAM symbols are carried in the delay-Doppler domain and experience the same channel response over the transmission/observation interval and extract the maximum diversity of the channel in both time and frequency dimensions. This allows the FEC layer to operate on a signal with uniform Gaussian noise pattern, regardless of the particular channel structure. OTFS has a natural architectural compatibility with OFDM, based on its underlying multicarrier components and the reference signal architecture supports any form of multicarrier modulation.

3GPP has identified a variety of eMBB deployment scenarios that focus on high vehicle speed and massive MIMO antenna arrays. The new radio air interface must support high spectral efficiency in high Doppler environments while supporting a large number of antennas. OTFS is ideally suited for these requirements, providing: high spectral efficiency; accurate channel estimation and prediction; and very efficient and flexible reference signals for massive MIMO applications.

Proposal 1: It is requested that the OTFS modulation and reference signal multiplexing scheme is thoroughly evaluated on its merits for the air interface of 5G systems and included in the Technical Report TR38.8XX "TR for Study on New Radio Access Technology Physical Layer Aspects".

4. References

[1] TR 38.913, "Study on Scenarios and Requirements for Next Generation Access Technologies".

[2] 38910-021 Draft 4: "Study on Scenarios and Requirements for Next Generation Access Technologies".

[3] R1-160671, "New SID Proposal: Study on New Radio Access Technology".

[4] R1-162930, "OTFS Waveform for New RAT," Source: Cohere Technologies.

[5] C.-L. I, S. Han, Z. Xu, S. Wang, Q. Sun, and Y. Chen, "New Paradigm of 5G Wireless Internet," *IEEE Journal on Selected Areas in Communications*, vol. 34, no.3, pp.474-482, 2016.