Orthogonal Sequence Division Multiplexing (OSDM) for 6G Air Interfaces

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OSDM Introduction

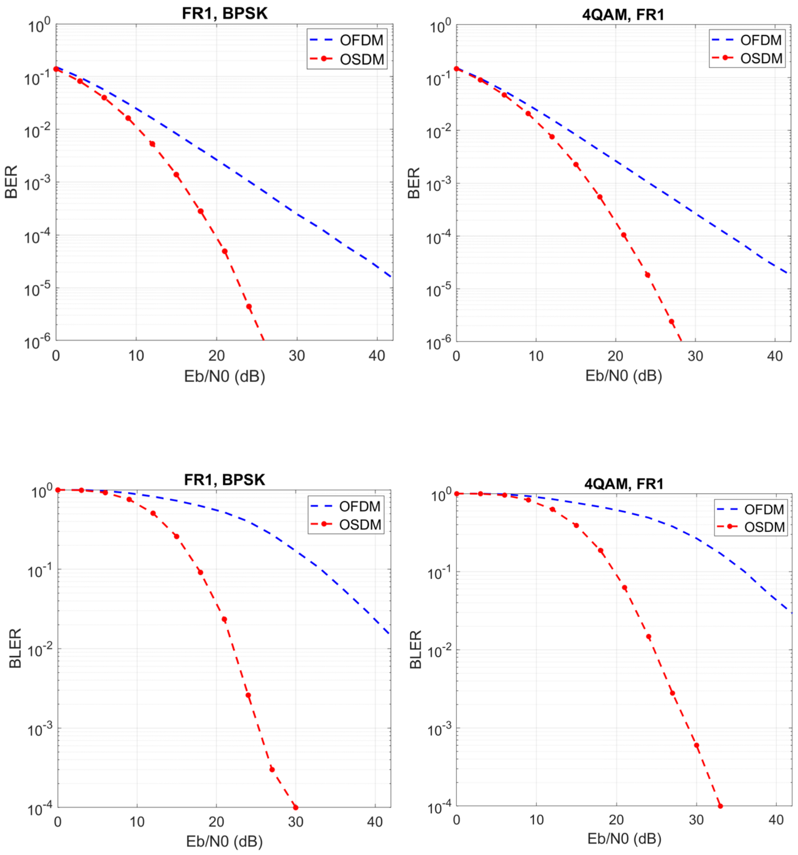
- Waveforms that enhance the reliability of a radio access network (RAN) air interface provide significant benefits in terms of improved spectral efficiency, energy efficiency, and network coverage. Achieving such enhancements through an evolutionary pathway without significantly changing system or silicon complexity is advantageous.
- The OFDM waveform used in 4G and 5G possesses many useful attributes, but for 6G OFDM exhibits reliability limitations in use cases such as ISAC, and in environments characterized by substantial delay Doppler (DD) spreads.
- For these reasons, 6G would benefit from a more reliable waveform especially one that can co-exist with and is compatible to OFDM in the expected 6G frequency bands (i.e., FR1, FR2 and FR3). One such waveform is Orthogonal Sequence Division Multiplexing (OSDM).
- OSDM, as proposed by the author, is a one-dimensional (1D) multiple-access scheme like OFDM, but operates in the time-code (TC) domain, in contrast to OFDM's time-frequency (TF) domain. Instead of mapping data symbols on to a TF-grid, OSDM maps symbols on to a TC-grid. OSDM occupies the same signal processing and resource-allocation resources as OFDM. That is, OSDMA and OFDMA are compatible and can coexist.
- OSDM is a generalization of the cyclic prefix direct sequence spread spectrum (CP-DSSS) concept [1, 2]. While CP-DSSS specifies rotated Zadoff-Chu sequences as its orthonormal basis function, OSDM admits any real or complex orthonormal basis function derived from a rotated root sequence with ideal or near-ideal auto-correlation properties. Also, non-Orthogonal Sequence Division Multiplexing (nOSDM) variants can be realised, for example, by using an M-sequence or Gold code as the rotated root sequence.
- The fundamental insight behind OSDM is that it interchanges OFDM's ideal cross-correlation properties of complex subcarrier waveforms with the ideal auto-correlation properties of a real or complex rotated root sequence. Each information symbol in OSDM experiences well defined autocorrelations over time and code.
- The OSDM waveform enhances system reliability over OFDM for a range of DD spreads, from low to high, and offers implicit support for ISAC applications [3].

OSDM in the 6G Air Interface

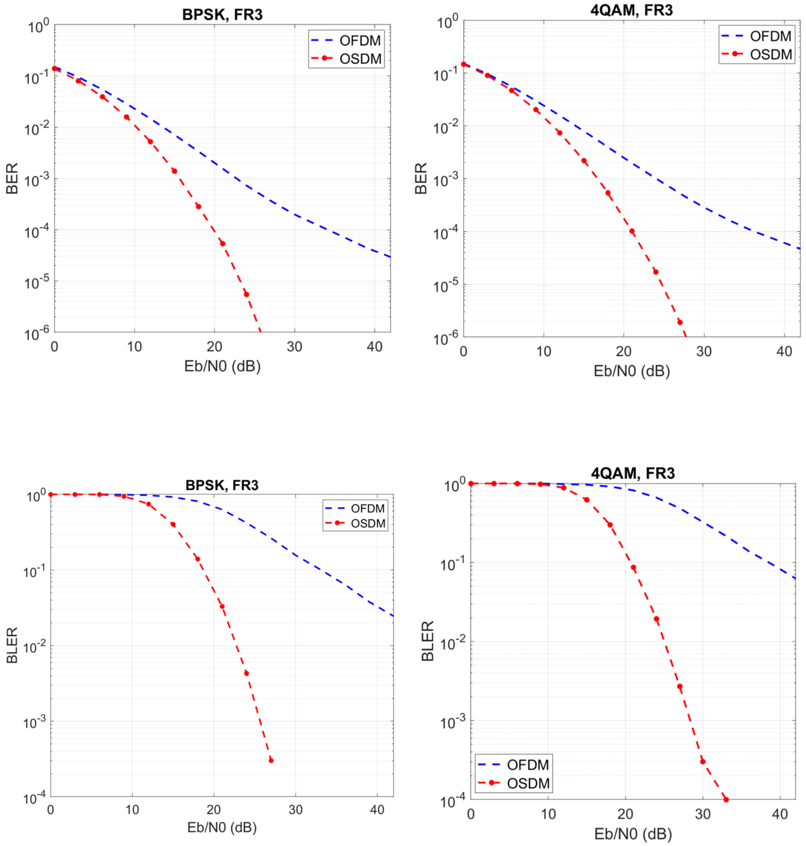
- In an air interface like 5G-NR, OSDM plays the same role as OFDM, multiplexing users' data on to a shared TC-grid in the same way OFDM multiplexes users' data on to a shared TF-grid. This compatibility enables OSDM and OFDM to coexist in a hybrid air interface.
- Like OFDM, OSDM takes a Layer-2 transport block and applies the conventional Layer-1 functionalities of CRC attachment, LDPC/Polar FEC coding, rate matching, scrambling, QAM mapping, layer mapping, MIMO precoding, resource mapping and OSDM waveform generation with a cyclic prefix. In doing so, OSDM uses existing DSP resources at the Tx and at the Rx where inverse operations are applied.
- Unlike OFDM, OSDM offers a larger and more varied transform space, which allows for the selection of waveforms with properties matched to diverse use cases and propagation environments, as required by 6G.
- OSDM uses the same pilot resources as OFDM, while admitting variants of conventional linear and non-linear equalisers that enhance system performance in low to high DD spread channels, as well as naturally exploiting PRACH and SRS waveforms based on Zadoff-Chu sequences as found in 5G-NR.
- The following slide depicts comparisons of the uncoded BER and BLER (i.e., PER) performance of OSDM cf. OFDM for BPSK and QPSK in representative DD channels when operating in FR1 (4 GHz), FR3 (17 GHz) and FR2 (28 GHz) bands for 500 km/h UE speeds, and TD LMMSE equalisation with ideal channel estimation.

OSDM vs. OFDM

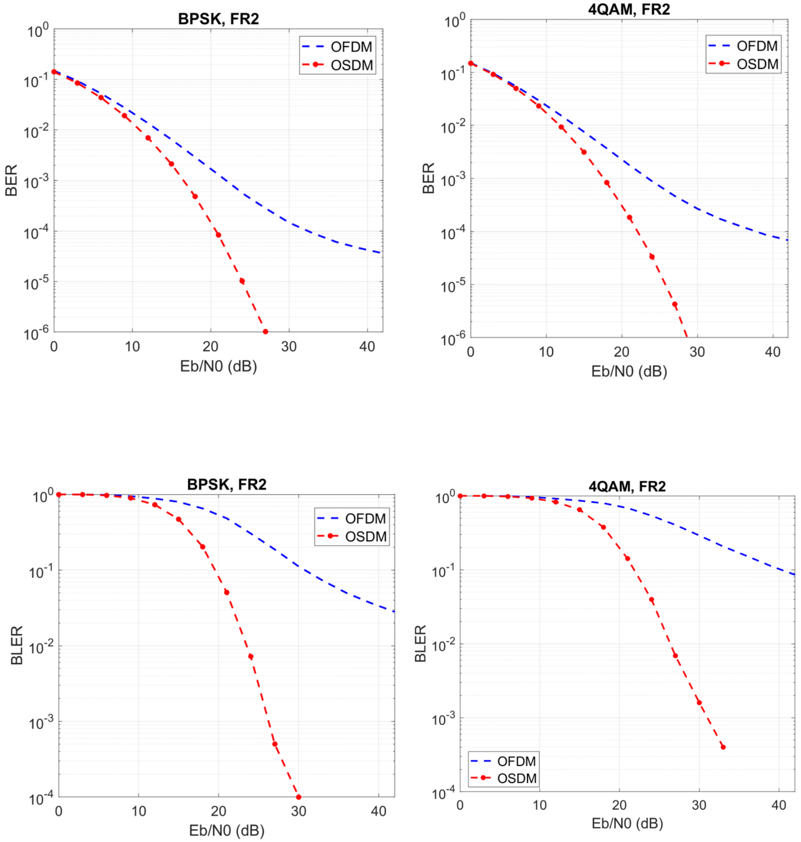
FR1



FR3



FR2



OSDM Benefits

- Introducing OSDM into 6G is proposed from the view-point of realizing significant system performance gains through a minimal change of system functionality and software/hardware realization. The proposed approach benefits stakeholders in the 5G and future 6G ecosystem.
- Chip manufacturers will be able to produce the next generation of modem chipsets and digital signal processors without incurring significant costs and risks to their existing technology. This stems from OSDM's comparable complexity to OFDM and its realization mostly through software changes. OSDM's benefits extend to the RF front end, where phase noise effects are potentially better mitigated than in OFDM.
- Cellular mobile vendors and OEMs will be able to develop larger product ranges for 6G's diverse use cases, which will operate more reliably across a larger range of challenging environments, especially high-speed environments. A reliable 6G ISAC solution would enable significant growth in joint sensing and communications hardware and software products.
- Cellular operators have a critical need to transform from 5G to 6G services within a manageable infrastructure investment framework. This requirement seeks to balance introducing beneficial capabilities by upgrading existing infrastructure to enhance capacity, coverage and energy efficiency while generating additional revenue from new services. OSDM promises such possibilities through its evolutionary approach.
- To become a successful 6G air interface waveform, OSDM should be evaluated by 3GPP to validate its potential and capabilities. Our results to date demonstrate OSDM's efficacy in 6G like use cases and environments. A full expression of these advantages through deeper contested simulation and empirical studies into beamforming, ISAC and ML-enabled performance could significantly benefit 6G.
- The University of Sheffield is committed to the advancement of 6G by makings its IPR accessible under fair, reasonable, and non-discriminatory (FRAND) terms.

Citations

[1] S. Henthorn, K. L. Ford and T. O'Farrell, "Direct Antenna Modulation for High-Order Phase Shift Keying," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 1, pp. 111-120, Jan. 2020, doi: 10.1109/TAP.2019.2935136.

[2] B. A. Kenney, A. J. Majid, H. Moradi and B. Farhang-Boroujeny, "Multi-user Capacity of Cyclic Prefix Direct Sequence Spread Spectrum with Linear Detection and Precoding," 2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall), Victoria, BC, Canada, 2020, pp. 1-6, doi: 10.1109/VTC2020-Fall49728.2020.9348755.

[3] L. Gehre, L. G. de Oliveira, A. Diewald, T. Zwick and B. Nuss, "CP-DSSS for Radar-Centric Integrated Sensing and Communication," 2023 20th European Radar Conference (EuRAD), Berlin, Germany, 2023, pp. 347-350, doi: 10.23919/EuRAD58043.2023.10289259.

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