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# Research Statement

## Faster-than-Nyquist Signaling

My general research interests span the broad areas of digital communications and digital signal processing. In particular, I am interested in designing higher spectrally efficient transmission communication systems. The spectral efficiency (SE), measured in bits/sec/Hz, is defined as the number of information bits carried per a given time and bandwidth and it can be improved by either changing the transmission time or bandwidth. However, the transmission time and bandwidth are related in the sense that one can be traded for the other. Additionally, they are limited and costly resources that in most cases we cannot afford to change them. Another possible way to increase the SE is to adopt higher order modulation, i.e., $M$-ary modulation; however, to increase the SE by 1, this will be at the expense of almost doubling the signal-to-noise ratio (SNR)—to maintain the same error probability—at higher values of $M$. That said, there is a need to find alternative and novel ways to improve the SE without increasing the transmission time, bandwidth, or the modulation order.

Conventional digital communication systems use orthogonal pulses for transmission in time-domain to avoid having intersymbol interference (ISI). The roots of such design principles stem from Nyquist theorem, where the time-domain transmit pulses are always orthogonal with respect to shifts by integer number of symbol duration. Since the time-domain transmit pulses are orthogonal to each other, the optimal detection process is simple and can be achieved on a symbol-by-symbol basis. Faster-than-Nyquist (FTN) signaling is a novel transmission technique that intentionally violates the Nyquist limit and transmits pulses at a rate beyond the Nyquist limit, and hence, ISI is unavoidable [1]. The basic idea of FTN signalling is that the time-domain transmit pulses are no longer orthogonal with respect to each other. To illustrate the idea of FTN signalling, consider the following linear modulation system

$$s(t) = \sqrt{E_s}\sum\nolimits_{n} a_n h(t - n\tau T),$$

where $a_n$ is the sequence of $M$-ary transmit data symbols, each with energy $E_s$, and $h(t)$ is a unit-energy pulse that appears every $\tau T$ with $T$ is the symbol duration and $\tau \leq 1$ is the FTN signaling acceleration parameter. Interestingly, James Mazo in 1975 showed that the minimum distance (and hence, the error probability) of uncoded transmission of BPSK FTN signaling using sinc pulses remains the same as its counterpart of Nyquist signaling as long as $\tau > 0.802$ [2]; this is known later as the *Mazo limit*. In other words, Mazo showed that up to 25% more bits can be transmitted in the same bandwidth at the same energy per bit while maintaining the error probability of Nyquist signalling. The full potentials of FTN signalling to increase the SE were later proved by showing that lower bounds on FTN signalling information rates are often higher than the information rates of Nyquist signalling [3, 4]. Such improvements in the SE comes at the expense of complex receivers to remove the ISI introduced at the transmitter. The FTN signalling concept has been already extended to other pulse shapes [5], nonbinary signalling [6], frequency domain [7], and multiple-input-multiple-output systems [8]. This clearly shows the importance of designing low-complexity detection schemes of FTN signalling to facilitate its practical applications [9,10].

My investigation of this interesting problem during the past 18 months resulted in two published IEEE journals [11, 12], one published flagship conference paper (ICC) [13], and several other IEEE journal papers under review/preparation. At Saskatchewan University, I will further explore/exploit the ISI structure known to the FTN signalling transmitter to design low complexity receivers with the help of precoding at the transmitter. Additionally, I will explore the integration of FTN signalling and index modulation to join the best of both worlds. As discussed, FTN signalling suffers from interference from adjacent symbols and luckily index modulation can transmit the same number of bits using fewer number of active data symbols, i.e., less interference from adjacent symbols. In other words, index modulation uses a subset of the indices called the active set (either time-domain symbols or frequency-domain subcarriers) to carry additional bits. The unused subset of time-domain symbols or frequency-domain subcarriers are not used for transmission, i.e., will be nulled. Identifying the operating region (time/frequency acceleration parameter, combinations of active/non-active subsets of index modulation, etc) and designing low-complexity detection schemes from FTN signalling and index modulation is still an open question especially given the sparse structure of the transmit signal.

References


[1] J. B. Anderson, F. Rusek, and V. O¨ wall, “Faster-than-Nyquist signaling,” Proc. IEEE, vol. 101, no. 8, pp. 1817–1830, Aug. 2013.

[2] J. Mazo, “Faster-than-Nyquist signaling,” Bell Syst. Tech. J., vol. 54, no. 8, pp. 1451–1462, Oct. 1975.

[3] F. Rusek and J. B. Anderson, “On information rates for faster than Nyquist signaling,” in Proc. IEEE Global Communication Conference (GLOBECOM), Dec. 2006, pp. 1–5.

[4] F. Rusek and J.B. Anderson, “Constrained capacities for faster-than-Nyquist signaling,” IEEE Trans. Inf. Theory, vol. 55, no. 2, pp. 764–775, Feb. 2009.

[5] A. D. Liveris and C. N. Georghiades, “Exploiting faster-than-Nyquist signaling,” IEEE Trans. Commun., vol. 51, no. 9, pp. 1502–1511, Sep. 2003.

[6] F. Rusek and J. B. Anderson, “Non binary and precoded faster than Nyquist signaling,” IEEE Trans. Commun., vol. 56, no. 5, pp. 808–817, May 2008.

[7] F. Rusek and J.B. Anderson, “Multistream faster than Nyquist signaling,” IEEE Trans. Commun., vol. 57, no. 5, pp. 1329–1340, May 2009.

[8] F. Rusek, “On the existence of the Mazo-limit on MIMO channels,” IEEE Trans. Wireless Commun., vol. 8, no. 3, pp. 1118–1121, Mar. 2009.

[9] A. Prlja, J. B. Anderson, and F. Rusek, “Receivers for faster-than-Nyquist signaling with and without turbo equalization,” in Proc. IEEE International Symposium on Information Theory, Jul. 2008, pp. 464–468.

[10] J. B. Anderson, A. Prlja, and F. Rusek, “New reduced state space BCJR algorithms for the ISI channel,” in Proc. IEEE International Symposium on Information Theory (ISIT), Jun. 2009, pp. 889–893

[11] E. Bedeer, M. H. Ahmed, and H. Yanikomeroglu, “A Very Low Complexity Successive Symbol-by-Symbol Sequence Estimator for Faster-than-Nyquist Signaling,” IEEE Access, vol. 5, no. 1, pp. 2169 - 3536, Dec. 2016.

[12] E. Bedeer, M.H. Ahmed and H. Yanikomeroglu, “Low-Complexity Detection of High-Order QAM Faster-than-Nyquist Signaling,” IEEE Access, vol. 5, no. 1, pp. 14579 - 14588, July 2017.

[13] E. Bedeer, H. Yanikomeroglu, and M. H. Ahmed, “Reduced Complexity Optimal Detection of Binary Faster-than-Nyquist Signaling,” IEEE ICC, May 2017, Paris, France.