A Unified Framework for Reference-Based Ultra-Wideband Signaling

Kyle Morrison, Cagatay Capar, Zhiguo Lai, and Dennis Goeckel
University of Massachusetts, Amherst, MA 01003, USA

University of Massachusetts Amherst

Abstract

One application area of significant interest for ultra-wideband(UWB) technology is in localization and low-to-moderate data rate communication. Due to implementation complexity concerns, many recently proposed systems have been based around transmitted reference (TR) or pulse-position modulation (PPM) architectures. In response to the difficulty in implementing the delay line in small integrated receivers for the original TR system, frequency-shifted reference (FSR) UWB systems were developed, which in turn motivated recent code-shift (CS)-UWB and code-multiplexed (CM)-UWB systems. All of the systems are unified into a general class of reference based systems for performance comparison. Performance is considered under both average and peak energy constraints. Under the latter constraint, it is important to consider methods of peak mitigation, so an extension of the tone reservation method employed in orthogonal frequency division multiplexing (OFDM) systems is applied to systems within the framework, often without the cost in bandwidth efficiency observed in standard OFDM systems. Differences across the class, as measured in terms of peak power, can often be larger than those measured versus average power.

Introduction

Impulse-based ultra-wideband (UWB) wireless communication systems have significant potential; in particular, the extremely wide bandwidth provides the ability to communicate at very high data rates, and provides significant frequency diversity versus multipath fading. In addition, UWB's small power spectral density provides the potential to coexist with existing narrowband systems, thus helping to solve the frequency allocation problem that often delays the implementation of new wireless-based applications. Hence, UWB communication systems have been considered for standardization for short range low-power wireless communications in both high data rate(IEEE 802.15.3) and low-to-moderate data rate (IEEE 802.15.4a)applications.

Many systems have been considered for receivers which include transmitted reference (TR-UWB, Fig 1,2), where reference and data signal are shifted in time domain, frequency shifted reference(FSR-UWB) where the shift takes place in the frequency domain and code multiplexed (CM-UWB), where shifting occurs through a set of orthogonal codes. All of these different receivers can be unified into a general framework for performance analysis and comparison . A method similar to tone reservation for OFDM will be used to reduce high peak-to-average-power ratio(PAPR). Results are presented to show the improvement of systems after peak reduction.

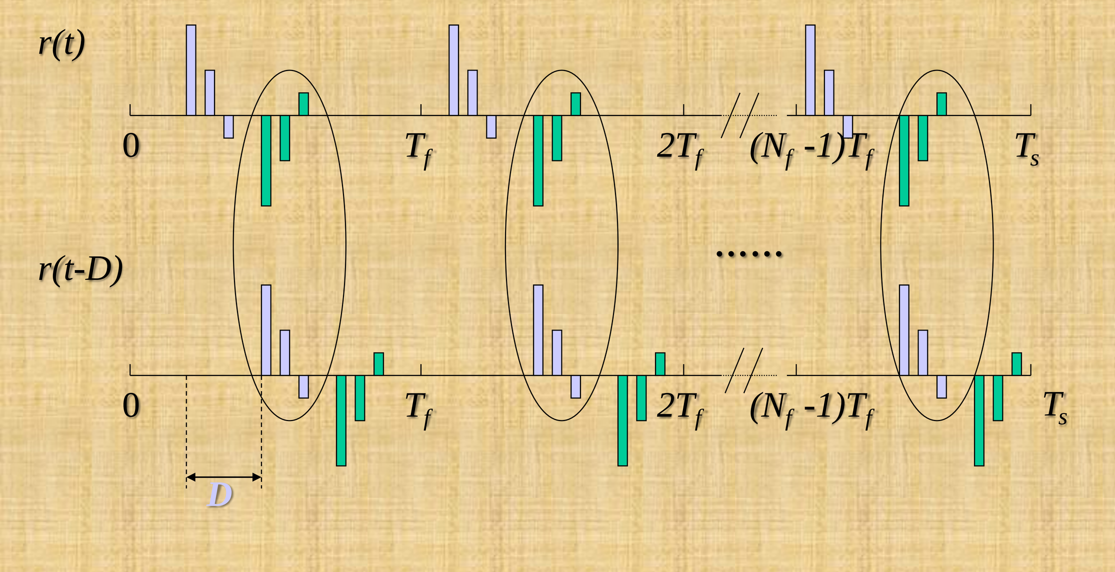

Fig.1. An example of TR-UWB receiving data bit = -1

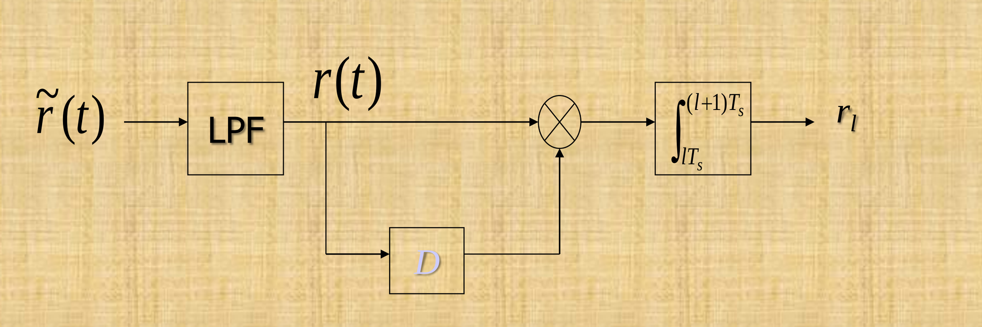

Fig.2. Receiver for TR-UWB. Note that D(Delay element) can be replace with a mixer to form FSR.

Receiver Model

The transmitted signal for the general framework of reference based systems is :

$$x(t) = \sqrt{E_r}\,u(t - lT_s) + \sum_{k=0}^{K-1} b_l^{(k)} \sqrt{E_d^{(k)}}\,\phi_k(t - lT_s)\,u(t - lT_s)$$

Below is the unified receiver model(Fig 3). Note that a single branch represents the single carrier case (i.e. TR, FSR, and PPM)

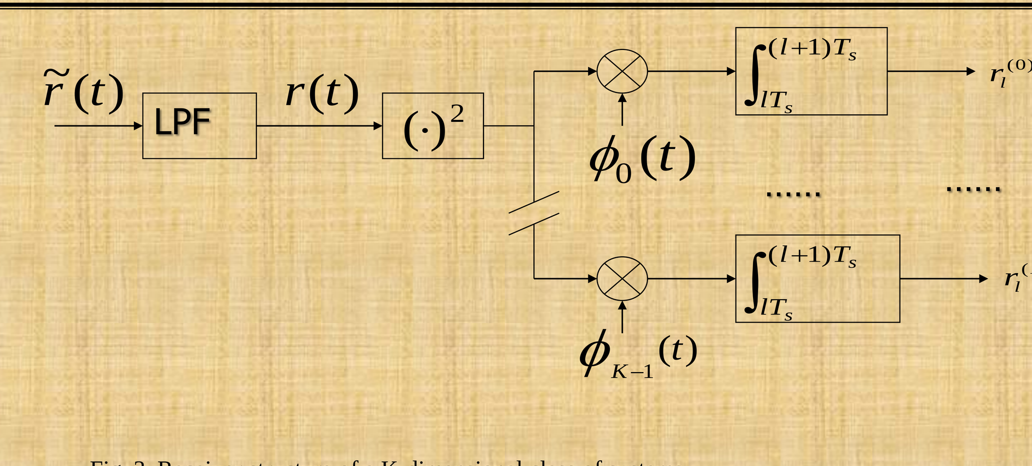

Fig. 3. Receiver structure of a K-dimensional class of systems.

Conclusions

❑ A common framework for noncoherent UWB systems that encompasses many promising recent noncoherent UWB systems has been considered.

❑ The choice of the optimal system depends largely on the application setting, particularly the choice of the number of frames per bit and the corresponding careful consideration of peak versus average signal constraints. Performance on AWGN channels is largely invariant to φ(t), its selection can have a significant impact on the performance of systems operating over multipath fading channels.

❑ Multi-differential FSR has the potential to greatly improve performance of the FSR-UWB system and through peak reduction techniques borrowed from OFDM, peak energy can be minimized .

Results

Optimality

Analytical and numerical results show that the optimal set of signals correspond to a signal with a broad autocorrelation function of φ(t) . This is dependent on the channel model since path spacing will vary across different channels potentially causing different amounts of interframe interference. Since small τ is of interest, this turns into a classic optimization problem where we find optimal values for the Taylor expansion of $R_\phi(\tau)$ about τ = 0 for all systems consider. The expression:

$$R_\phi(\tau) = 1 + \left(\frac{d}{d\tau} R_\phi(\tau)\,|_{\tau=0}\right)\tau + \frac{\left(\frac{d^2}{d\tau^2} R_\phi(\tau)|_{\tau=0}\right)\tau^2}{2}$$

for small τ, the τ term will dominate; if it is zero the τ^2 term will dominate…etc. The second term can potentially be zero(i.e. FSR) and the third term will only be zero for non-applicable solutions. This yields FSR-UWB as the optimal solution because it degrades quadratically with small τ in comparison to PPM. Below are simulation results that support the conclusion that systems with broad autocorrelation demonstrate better system performance in a multipath environment (Fig 4,5).

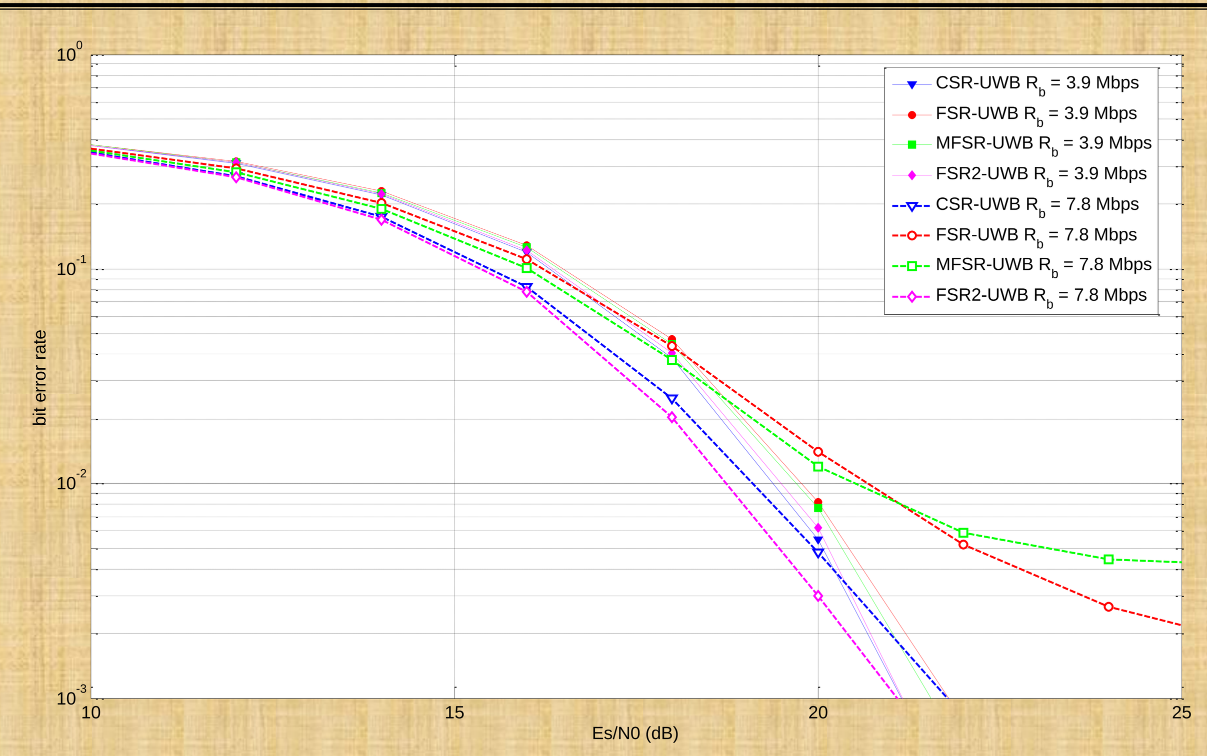

Fig . 4. Performance of various binary schemes on the IEEE 802.5.14a indoor LOS model (CM3) with a fixed frame time of Tf = 16 ns, Nf = 8 (dashed curves) and Nf = 16 (solid curves) which correspond to Rb = 7.8 Mbps and 3.9 Mbps, respectively.

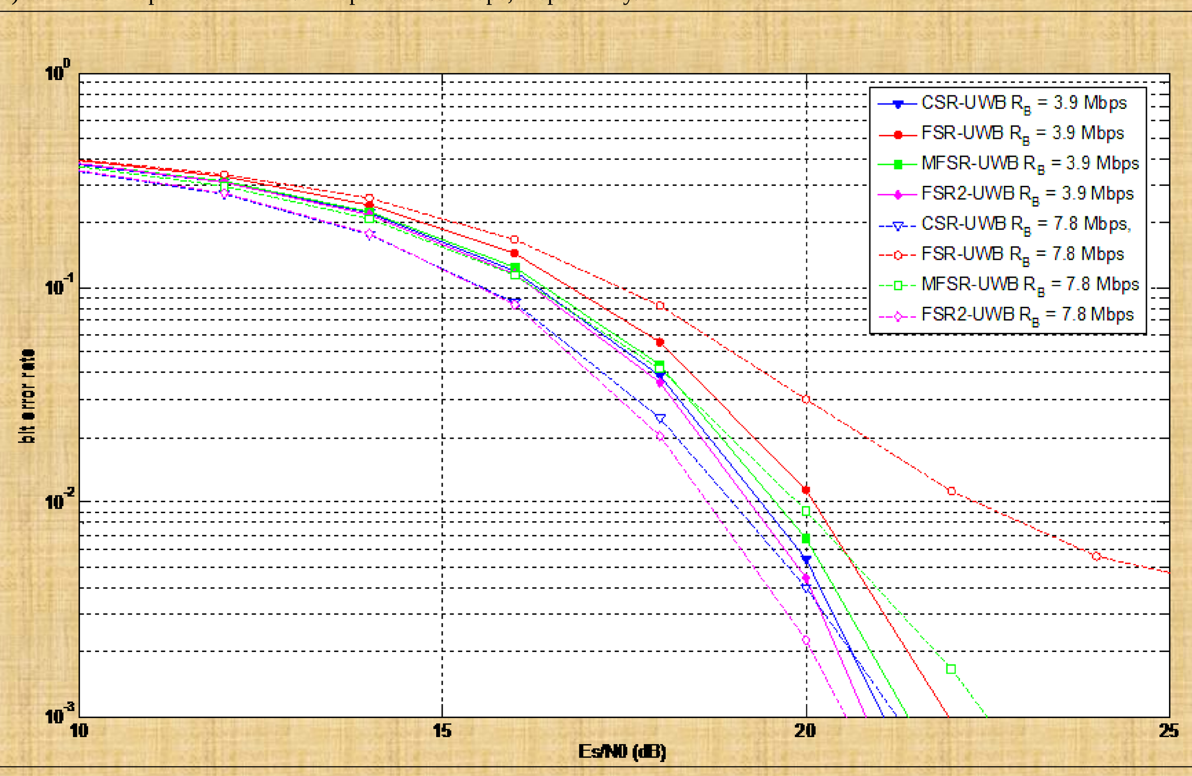

Fig. 5. Performance of various binary schemes on the IEEE 802.5.14a indoor NLOS model (CM4) with a fixed frame time of Tf = 16 ns, Nf = 8 (dashed curves) and Nf = 16 (solid curves) correspond to Rb = 7.8 Mbps and 3.9 Mbps, respectively.

Tone Reservation

Multicarrier Differential FSR(MD-FSR) has the disadvantage of a high peak-to-average power ratio (PAPR). Methods from OFDM have been explored to achieve peak reduction for MD- FSR. The method desirable here is one analogous to tone reservation, where some of the carriers are reserved for peak reduction (Fig 6). Here additional carriers called peak reduction carriers are used to mitigate the peaks of the high power data carriers. Note that these carriers are used at a minimal cost of data rate because of additional carriers. The carriers are orthogonal and don't affect the performance of data detection and can be used above the coherence bandwidth constraint because they don't need to pass through the same channel as the reference signal. This results in an optimization problem of introducing maximum peak data carriers constraint on an average power constraint. Below is a table that shows the initial peak and final peaks of CM-UWB and FSR-UWB after peak reduction (Table 1).

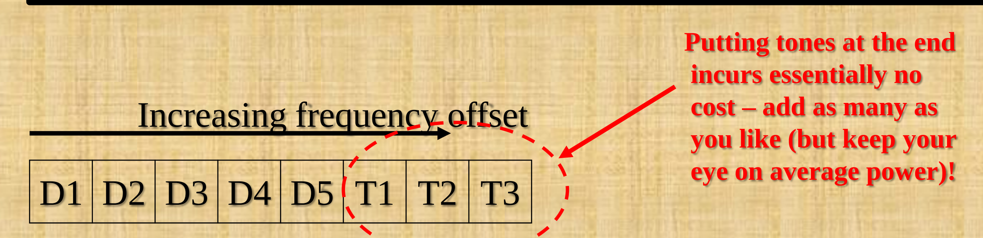

Fig . 6. Tone Reservation (5 data "D", 3 extra tones "T")

	Initial Peak	Initial and Final Energy	Peak Reduction (dB)	Final Peak
FSR, K = 4	0.8263	1, 1.7847	2.927	0.5899
CSR/CM, K=4	0.6475	1,1	0	0.6475
FSR, K=2	0.6475	1, 1.3185	2.1436	0.5059
CSR/CM, K=2	0.5211	1, 1	0	0.5211
FSR, K=1	0.5211	1, 1.0978	1.1605	0.4559
CSR/CM, K = 1	0.4317	1, 1	0	0.4317

TABLE 1 PEAK REDUCTION RESULTS FOR CSR/CM-UWB AND FSR-UWB SCHEMES (Nf = 128, Tf = 31.25 ns, AND D = 20)

Bibliography

[1] D. Goeckel and Q. Zhang, "Slightly Frequency-Shifted Ultra-Wideband (UWB) Communications", IEEE Transactions on Communications, Vol. 55: pp. 508-519, March 2007.

[2] D. Goeckel, J. Mehlmann, and J. Burkhart, "A Class of ultra wideband (UWB) systems with simple receivers", Proceeding of the Military Communications Conference, October 2007.

[3] Q. Zhang and D. Goeckel, "Multi-differential slightly frequency-shifted reference ultra-wideband (UWB) radio", Proceedings of the Conference on Information Sciences and Systems, March 2006.

[4] A. D'Amico and U. Mengali, 'Code-Multiplexed UWB Transmitted-Reference Radio," submitted to the IEEE Transactions on Communications.

This work was supported by the National Science Foundation under Grant ECS-0725616 and by the STTR Program of the Army Research Office