A NEW SIGNAL DETECTION METHOD FOR TR-UWB
By Time Delayed Sampling & Correlation (TDSC)

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Abstract: This paper introduces a new signal detection method for Low cost, Low power and Low complexity (L3) TR-UWB systems for medium to low data rate applications such as sensors networks. This new detection method is based on a time_to_space conversion realizable by an analog waveform sampler. This method overcomes the major difficulties in a traditional TR-UWB detection methods based on wide band delay lines. Finally the relaxed timing precision needed in symbol synchronization contributes further to lower the system power consumption. This concept has been validated by simulation with real data from experimental setup. The results will be presented and compared also with other solutions.

1 INTRODUCTION

Many applications (Metha, 2004), (Oppermann, 2004), (Duo, 2004) require low cost, low power and low complexity (L3) short range wireless communications means. Most of the current wireless communications systems are designed for the data transmission in a computer related context and do not satisfy completely these criteria. Our motivation in this research activity is to design wireless communications devices with L3 characteristics based on Impulse Radio (IR) UWB concept. The apparent hardware simplicity of an UWB system, hides a lot of design challenges (Bettayed, 2003). The high switching speed for the short duration UWB signal generation and the high timing resolution for UWB signal detection and synchronization between transmission and reception generate a considerable extra hardware complexity associated with very important power consumption overhead.

In an impulse radio based UWB system, the pulse generation can be implemented by using fast switching devices such step recovery diode (SRD) with a reasonable power consumption and complexity. This is not the case for UWB pulse detection.

Two main UWB detection methods can be distinguished.
The coherent detection method, based on a signal correlation between the incoming UWB signal and a local generated template (Time Domain, 2001), (Mielczarek, 2003), is requiring channel estimation.
The other one is based on non-coherent energy detection method (Doré,2005), (Stoica, 2005).

Theoretically speaking the coherent method gives better detection result than that of the non-coherent one.
But in reality, the high precision synchronization and local template generation in a multi-path environment are extremely difficult to be implemented with simple hardware.
Many UWB receivers use some number of analog correlators to collect the signal energy in front-end rake receiver architecture. The need to capture a large amount of the transmitted energy involves to use a great number of paths, besides the propagation which deforms the pulses shape, path to path, leads to a very high complexity both on hardware and software (estimation channel) (Durisi, 2004).

Some non-coherent detection based simple systems use signal energy detection which consists of measuring the energy in the incoming signal. The detection efficiency of this method is conditioned by the degree of the temporal energy concentration of

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an UWB signal. This detection method is usually implemented by using fast switching devices such as Schottky diodes or tunnel-effect diodes.

In spite of obvious hardware simplicity, this type of methods presents several limitations. The necessary low-pass post-filtering decreases considerably the amplitude of the signal at the output of the detector, spreads out this same signal over the axis of time. This leads to a much lower temporal discrimination power than that of initial UWB impulses and results in an unacceptably low sensitivity. Fig. 1 gives the comparison between the instant signal power and the low pass filtered signal. We can observe an important loss of signal amplitude due to the energy dilution in time.

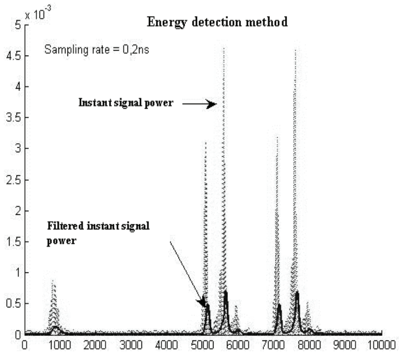


Figure 1: Energy detection systems.

From these observations, we think that the Transmitted-Reference (TR) UWB architecture (Rushforth, 1964), (Hoctor, 2002) could be a solution to our L3 UWB systems for several reasons. Firstly in TR-UWB system, each transmitted signal pulse is preceded or followed by a reference pulse. Due to the short time duration between these pulses, the propagation channel can be considered as constant and the two pulses will keep a strong correlation at the reception point even in a strong multi-path environment. So the TR-UWB signal can be detected by using a pseudo coherent scheme where the TR-UWB signal is correlated with a time delayed copy of this signal as shown in Fig. 2. Secondly the time delay between the signal pulse and the reference pulse can be seen as a parameter of signal diversification for channel coding and multiplexing. Besides TR-UWB can be as efficient as Rake-receiver for energy collection (Zasowski, 2004), but with a much simpler hardware.

Despite the advantages of TR-UWB, the major difficulty in the realization is the broadband delay line with wide bandwidth, highly linear phase, perfect impedance adaptation and highly stable delay (Goeckel, 2005). An implementation using transmission line presents several problems, especially the delay precision and stability. The lack of real-time programmability is another limitation in a real exploitation of TR-UWB. Moreover, a real transmission line presenting an exploitable delay value remains impossible to integrate in a miniature circuit simply because of its physical dimension.

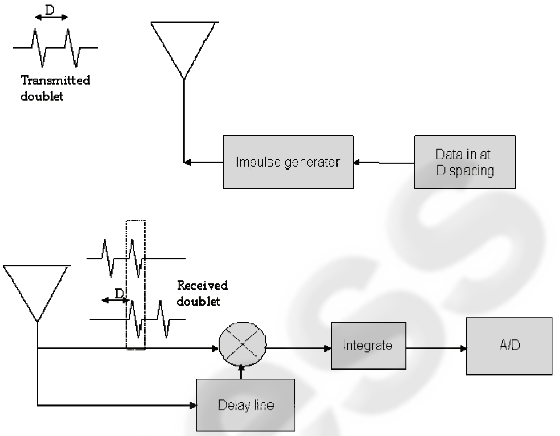


Figure 2 : Simplified TR-UWB communication system.

In this article we proposed a very different approach based on a time-space conversion using an analog sampler. The TR-UWB signal is sampled by two analog waveform samplers with pre-defined delay which matches the time delay between the pulses in a TR-UWB frame. The signal detection will be done by applying a waveform correlation between the two TR-UWB signal samples. We called this new concept for UWB data transmission, the Time Delayed Sampling and Correlation (TDSC) which will be detailed in section II. In section III, we will report the first experimental validation results made in different propagation conditions. These results demonstrate the potential advantages of this TDSC concept in L3 UWB communications systems. Finally in section IV, we will give some conclusions and perspectives in this research works.

2 TDSC - A NEW APPROACH FOR TR-UWB SIGNAL DETECTION

Recently, other fields such as the physics of high energy particles use high speed waveform samplers in order to capture and record highly impulsive signals from different detectors. These signals have the similar temporal and electrical properties as those of UWB. The most significant work is done by (Kleinfelder, 2003) in CMOS technology. The realized circuit can capture several hundred points of a signal at 10 GHz sampling rate.

Our proposed TDSC detection scheme is highly inspired from this work. The analog waveform sampler as shown in Fig. 4 uses an asynchronous delay line composed of simple inverters to generate the sampling commands at the different moments. This asynchronous implementation permits a sampling rate much higher with much lower power consumption than that of a synchronous design by using a global and explicit clock.

By using two waveform samplers as shown in Fig. 3, one is activated at the instant T and the other at T+D, two time delayed and sampled waveforms of a TR-UWB signal can be obtained. If a TR-UWB signal pulses fall in these sampling windows, we will have two similar waveforms because the double pulses in a TR-UWB frame have the same waveform distortion after the propagation in a time invariant channel as explained in section I. The absence of TR-UWB signal will result in two totally independent waveforms from the samplers. By consequent, the TR-UWB signal detection here can be easily done by using a simple correlation operation between the time delayed sampled waveforms. This principle is called Time Delayed Sampling and Correlation. Fig. 5 gives a graphical representation of this detection concept.

By using this method, we can see that the TR-UWB will be sampled twice with a constant time delay. The role of the broadband delay line is replaced by a time delayed double sampling which removes completely the need of an explicit analog signal delay line and all the design difficulties associated with. In this case, the delay is only applied to the sampler's command digital signals, which can be generated easily and programmably in real-time from the system clock with an extremely high precision and high stability. So the parameter D in TR-UWB can be used for channel coding and multiplexing. Fig. 3 gives the overall structure of TDSC (Ni, 2005).

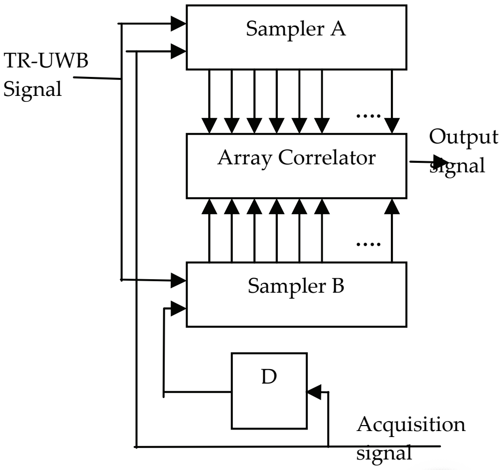


Figure 3 : General scheme of Time Delayed Sample & Correlation system, based on two samplers temporally delayed.

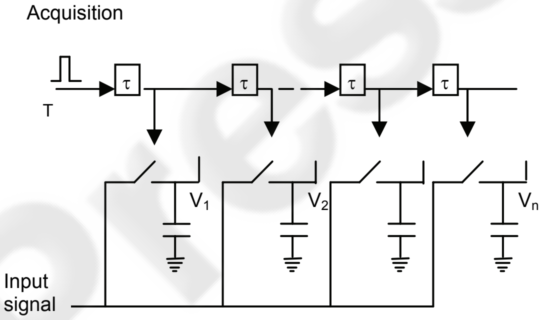


Figure 4 : The principle of an asynchronous delay line based analog waveform sampler.

The TDSC detection cannot be done continuously in time. So a synchronisation between the TDSC operation and the incoming TR-UWB signal is needed. But in contrast to other detection methods (Time Domain, 2001), TDSC method imposes much lower constraint on the precision of this synchronisation. As shown in Fig. 5, when the UWB pulses fall inside the sampling windows, it can be detected reliably.

This means that the timing precision for this synchronisation is indexed at the TR-UWB frame duration which is much larger than that for pulse detection.

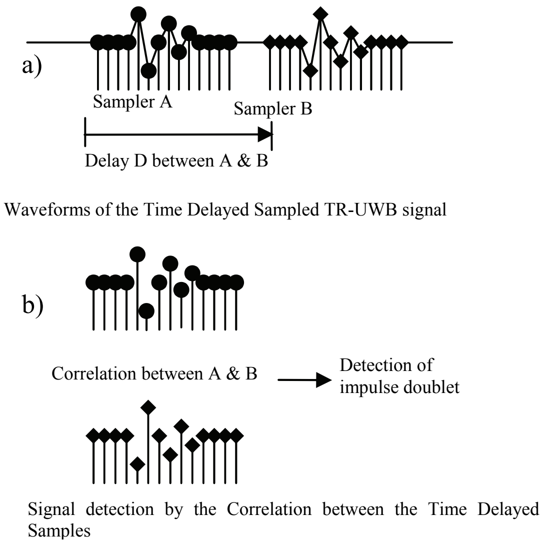


Figure 5: Principle of TDSC method. a) Waveforms of the time delayed sampled TR-UWB signals captured by the samplers A and B. b) The detection of impulse doublet is obtained with a simple correlation operation of the two delayed sampled waveforms.

This low timing precision necessary in detection synchronisation reduces not only considerably the signal acquisition time but also the complexity of synchronisation tracking. This characteristic is particularly interesting for sensor networks like applications where the data transmission is sporadic with very low duty cycle. The fast acquisition and tracking can reduce significantly the system power consumption by reducing the activation time which is often conditioned by acquisition time for small data packages.

3 EXPERIMENTAL VALIDATION

TDSC detection method has been validated by using simulation on the data captured from an experimental setup. This experimental setup gives realistic input signals for the TDSC simulation program in order to be as close as possible to the real TR-UWB working conditions. The results of the validation give some design guide to further VLSI implementation.

3.1 Experimentation Setup

The experimentation setup is shown in Fig. 6. We used a off the shelf pulse generator in order to generate a rectangular pulses train as shown in Fig. 7. The symmetric rising and falling edge transition time is less than 5ns (Pulse Generator E-H research laboratories model 137A), and we set the rectangular pulse width to 100 ns.

A simple thick monopole antenna has been used for this experimentation. The inevitable ringing in this kind of antenna permits to test the tolerance of TDSC detection method vis-à-vis to the impedance adaptation problems in real implementation. Monopole antennas will reshape the digital pulses into wide band limited pulses. So the rising and falling edges of each digital pulse will generate an impulse doublet with opposite polarities and a temporal delay D corresponding to the digital pulse width. Then, the impulse doublets are sent, propagated in an indoor environment and received by a digital oscilloscope with memory of 300MHz bandwidth. An example of the captured TR-UWB signal is shown in Fig. 8. Finally, we use the Matlab software to simulate the TDSC detection method on these sampled TR-UWB signals.

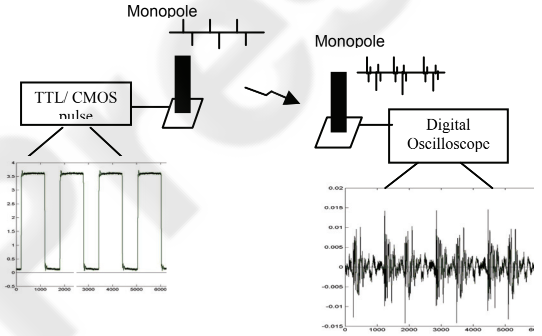


Figure 6: Experimentation setup: A off the shelf pulse generator, two monopole antennas and a digital oscilloscope as sampler, were used.

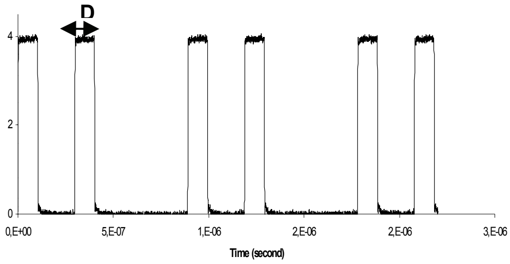


Figure 7: Rectangular input signal. The temporal delay D between the two pulses of the doublet is around 100ns. Two doublets will be separated by 300ns. A silence space between two couple of doublets is equal to 500ns.

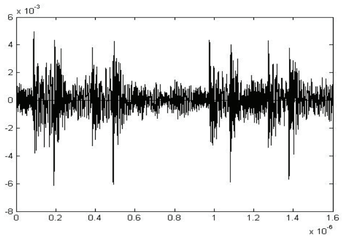
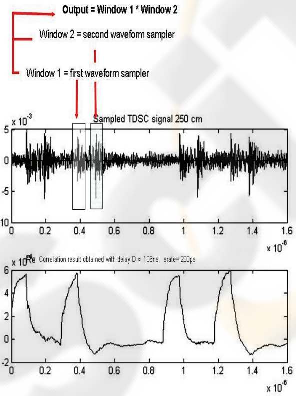


Figure 8: Real output doublets sampled and recorded thanks to a digital oscilloscope. The reference pulse and the data pulse are separated by a temporal delay D.

3.2 Experimentation Results

In the TDSC principle, the TR-UWB signal detection is done by correlating two temporally delayed sampled TR-UWB signal. This is simulated by applying cross-correlation function to two temporal windows on the recorded TR-UWB signal. These temporal windows correspond to the double time delayed waveform samplers. In order to skip at first the problem of synchronisation, these windows will slide on the recorded TR-UWB signal in a contiguous way, as shown in Fig. 9-a. In the same figure (Fig. 9-b), the result of the simulated TDSC detection method with a TR-UWB signal sampled at 5Ghz rate (200ps). It is demonstrated that the basic cross correlation function gives a satisfied results and the virtually null output during TR-UWB signal absence makes the decision threshold setting very easy.

In order to evaluate the performance of TDSC method, different configurations and parameters have been tested.



a)

b)

Figure 9: a) Principle of the algorithm used to validate the TDSC concept. One sampling window is sliding on another window about a fixed temporal delay equal to D. b) Correlation result between the two sampled signals. Here the sampling rate was equal to 0,2ns.

In the above example, the receiving antenna was placed 250 cm away from the transmitting antenna with the same height.

Many others measurements were carried out where the distance varied from 80 cm to 5 meters, with constant emission power. The sampling rate also varied from 200ps to 2ns. For all these cases, the TDSC method gave very good detection performance. Note that above a 2ns sampling rate, the TDSC detection failed. This is consistent with Shannon theorem.

These results are very promising for the TDSC concept and the future realization circuits. Based on these promising results we decided to investigate others properties of TDSC method.

3.2.1 Synchronisation Tolerance and Temporal Discrimination

The high speed impulses used in IR-UWB need a high precision temporal synchronisation between the transmitter and the receiver. In a classic IR-UWB system, this temporal synchronisation precision should be higher than the minimum pulse width. This requirement represents one of the major challenges in a real hardware implementation.

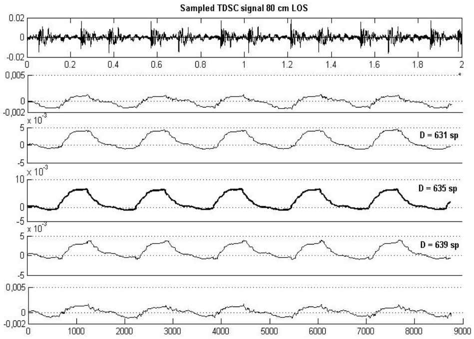
In the TDSC method, the detection can be effective when the impulse doublet falls inside the temporal sampling windows. This means that the temporal synchronisation precision is indexed to the symbol rate but not that of individual impulses. The maximum width of the sampling window is to the delay D and this gives a large synchronisation facility and tolerance.

But another interesting point here is that this large synchronisation tolerance has no impact on the temporal discrimination power of the TDSC detection because the temporal discrimination power of the TDSC method is conditioned by the cross-correlation function applied onto the sampled signals. This high temporal discrimination capability is illustrated by the following aspect: - the separation between two pulses inside a TR-UWB doublet.

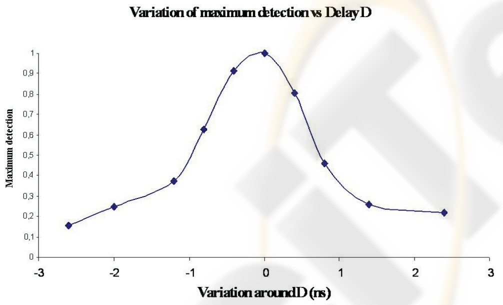
In order to code one data bit, two pulses are transmitted, separated by a known delay D. This delay can be seen as selectivity parameter (similar to frequency in a frequency division system) at the reception. A high selectivity based on this parameter can not only reduce noise but also give higher channel capacity for coding and multi-access.

In order to validate this selectivity, we carried out simulations by varying the delay D at TDSC detection stage for a recorded TR-UWB signal with D=127ns at transmission here. We varied the value of D +/-10 sampling points around its nominal value. The simulation result is shown in Fig. 10. Here the sampling period is 200ps, the temporal discrimination can be evaluated at +/-2ns.

This characteristic can not be found in other detection methods. For example, an energy detector integrates all incoming energies and results in a low temporal discrimination. Besides some information on the incoming signal can be lost such as pulse polarity. The coherent detection method gives a theoretically better performance but the difficulties in the local template generation and ultra-high precision synchronisation make it impractical in simple low cost and low power systems.



(a)



(b)

Figure 10: a) TDSC results for small variations around the value of delay D. b) The variation of the maximum detection versus D.

3.2.2 Detection and MP Energy Collection under LOS & NLOS Contexts

We conducted experiments with and without a line of sight propagation path in order to evaluate the performance of TDSC detection in the two cases. For the first case (Fig. 11), the two monopole antennas are in line-of-sight, at a distance of about 2,50 meters. The second case (Fig. 12), is performed with a metallic obstacle between the two monopole antennas, in order to obtain a non line-of-sight scheme.

In a multi-path (NLOS) context, the received TR-UWB impulse doublets can be strongly confused together as shown by the upper waveform in Fig. 12. When the TDSC method is applied to this signal, the successive TR-UWB doublet can be clearly separated and detected, despite the energy spreading as shown in the lower waveform in Fig. 12.

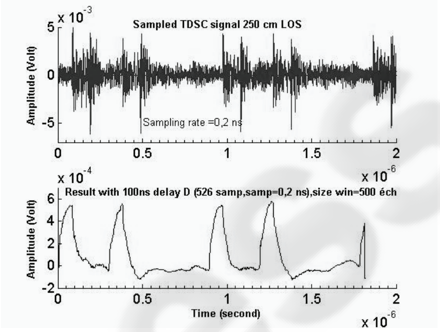


Figure 11: Simulation result for LOS experiment.

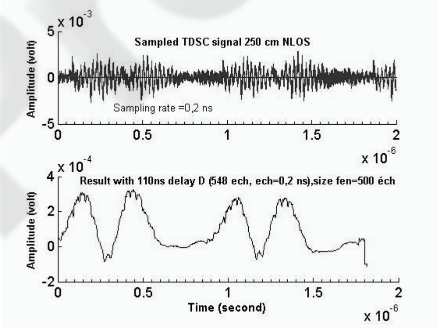


Figure 12: Simulation result for NLOS experiment.

4 CONCLUSION & PERSPECTIVES

In this paper, we have introduced a new TR-UWB signal detection concept -The Time Delayed Sampled and Correlation (TDSC). This method has been presented in details and validated experimentally. This detection method gives numerous advantages such as large synchronisation tolerance, high multipath signal energy collection efficiency in strong multi-path environment, high signal selectivity and modular CMOS friendly design with low power consumption, etc. Actually this validation has been done in 300MHz band, a

CMOS waveform sampler circuit capable to operate at 10GHz is on the way and this circuit will permit a full validation at the lower end of FCC UWB band. In parallel, the theoretical investigations on this method by using different channel models proposed by IEEE P802.15-WPANs (Foerster, 2003), (Molisch, 2003) are on the way.

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