# Intermediate Report Nr. 6

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## 1 Modelling the uncertainty from integration

It is well known from literature ( [1]) that the minimum achievable error is linked to the sampling/integration period used for energy detection. For a uniformly distributed location of the line-of-sight component within the according integration interval, one can reduce the minimum achievable mean absolute error to $\frac{T_i}{4}$ by centering the TOA estimation within the integration interval. Still, it is questionable how such an uncertainty can be modelled for simulation purposes without adding systematic errors to the simulation results. This document tries to explain the approaches done so far and how they can be employed for the remainder of the work.

**The old version:** In a first run of simulations performed last year the uncertainty was modelled by just adding $\frac{T_i}{4}$ to the results, which actually DID deliver plausible results, but which obviously simplified the problem a bit too much.To say it in some kind of verbal vector notation:

*The nth element of* $\mathbf{x}$ *is the leading edge, and the nth element of* $\mathbf{t}$ *is zero. The nth element of* $\mathbf{x}$ *is aligned to the nth element of* $\mathbf{t}$.

**Shifting the received signal time vector:** A second way to model this uncertainty was performed by just shifting the time instant vector of the signal fed into the integrator by a random time $t_{add} \in \{-\frac{T_i}{2}, \frac{T_i}{2}\}$. With that, even if the correct energy block was detected, a, error equal to $t_{add}$ was obtained, finally resulting in the expected mean absolute error.

However, by looking at how the integrator calculates the series of energy samples, it gets obvious what the problem of that approach is: The integrator is fed with the received signal, where always the first $N_i$ samples, then the next $N_i$ samples and so on are summed up representing the energy contained in these samples. The according energy vector time instants where taken from the center of the interval, by just accessing the corresponding element in the vector of received signal time instants. Thus, the integrator always centered its first sample around the actual leading edge, whereas only the time vector was shifted relatively to the signal vector to simulate the uncertainty. The problem with that approach now is, that by doing so the integration window is still synchronized to the actual leading edge, making a successful detection of the leading edge block more likely. This problem, however, cannot be neglected as suggested by looking at Fig. 1, because the minimum error would be much smaller than it actually is.

*The nth element of* $\mathbf{x}$ *is the leading edge, and the nth element of* $\mathbf{t}$ *is* $\pm\frac{T_i}{2}$. *The nth element of* $\mathbf{x}$ *is* ***not*** *aligned to the nth element of* $\mathbf{t}$.

**The ideal version – shifting the channel impulse response:** The right way to model this uncertainty is to shift the time vector of the CIR, so that the compound CIR and consequently also the received signal is shifted itself. This on the other hand results in the fact that the leading edge is not synchronized to the center of the integration interval anymore, and consequently the detection of leading edge is less likely than in a synchronized scenario.

*The nth element of* $\mathbf{x}$ *is* ***not*** *the leading edge, and the nth element of* $\mathbf{t}$ *is* $\pm\frac{T_i}{2}$. *The nth element of* $\mathbf{x}$ *is aligned to the nth element of* $\mathbf{t}$.

However, the problem with that approach is the following: Assuming that each and every ranging algorithm introduced (direct, parallel, sinc, sliding) has a different uncertainty, for all of these algorithms a different compound CIR, received signal, and filtered received signal has to be computed, resulting in a much higher computational complexity. Thus, to make computation faster and more efficient, a slight simplification was introduced

**The approximately ideal version – shifting the received signal vector:** In this simplified approach the compound CIR, the received signal, and the filtered received signal has to be calculated only once per channel or per channel and $\frac{E_s}{N_0}$, respectively. It bases on the simplification that uncertainties in the order of the resolution interval of the simulation (`md.T_s`) can be modelled by just shifting the received signal time instant vector accordingly. Naturally, this assumption hold better, the higher the resolution is. The uncertainty was now modelled by

1. shifting the received signal time instants vector by adding $t_{add}$ and
2. shifting the received signal vector by $\left\lfloor \frac{t_{add}}{\texttt{md.T\_s}} \right\rfloor$.

The latter operation was performed by either stuffing the according number of zeros at the beginning of the vector[1] or by just deleting the first few elements. This way the ideal approach is approximated to a wide extent without causing a too high complexity (see Fig. 2). In other words:

*The nth element of* $\mathbf{x}$ *is* ***not*** *the leading edge, and the nth element of* $\mathbf{t}$ *is* $\pm\frac{T_i}{2}$. *The nth element of* $\mathbf{x}$ *is* ***not*** *aligned to the nth element of* $\mathbf{t}$.

# References

[1] I. Guvenc and Z. Sahinoglu, "Threshold-based TOA estimation for impulse radio UWB systems," in *ICU 2005. IEEE International Conference on Ultra-Wideband.*, 09 2005.

[1] This, of course, adds another inaccuracy or simplification. I just assumed that these 2-4 samples at the beginning of the preamble would not cause any problems, since we are averaging the whole result over at least 16 symbols nevertheless. However, as soon as I can think of an, easy, low-complexity way out of that problem, I will definitely try to implement it.

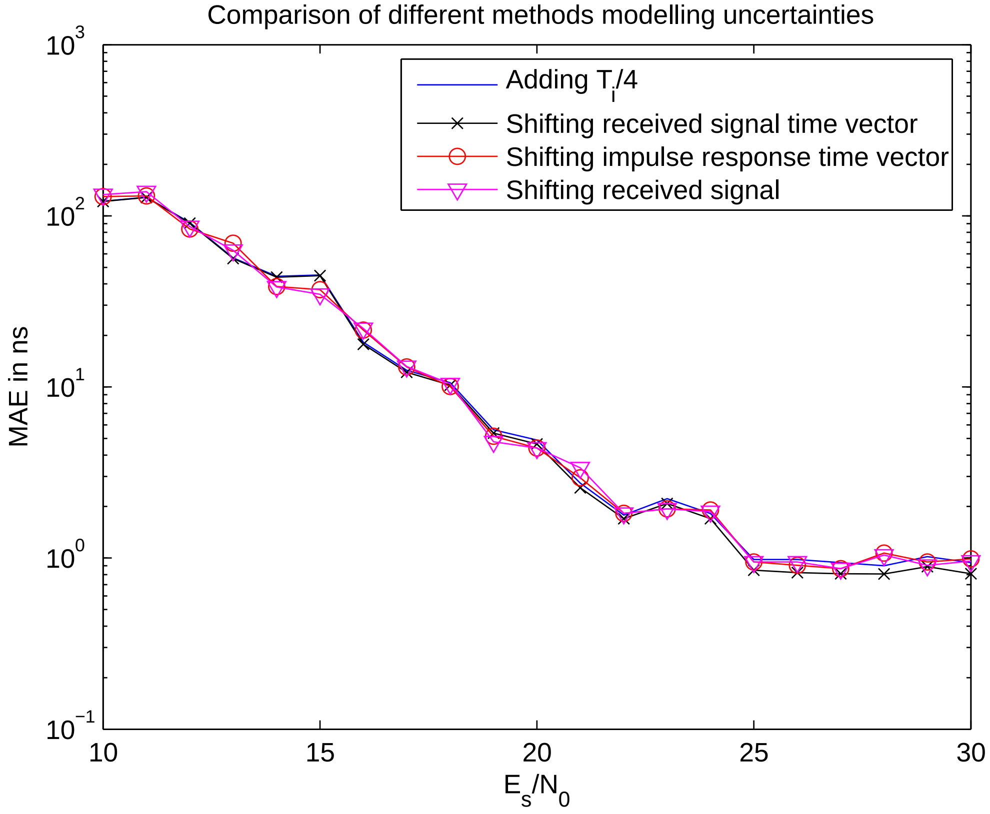


Figure 1: Different ways of modelling uncertainties

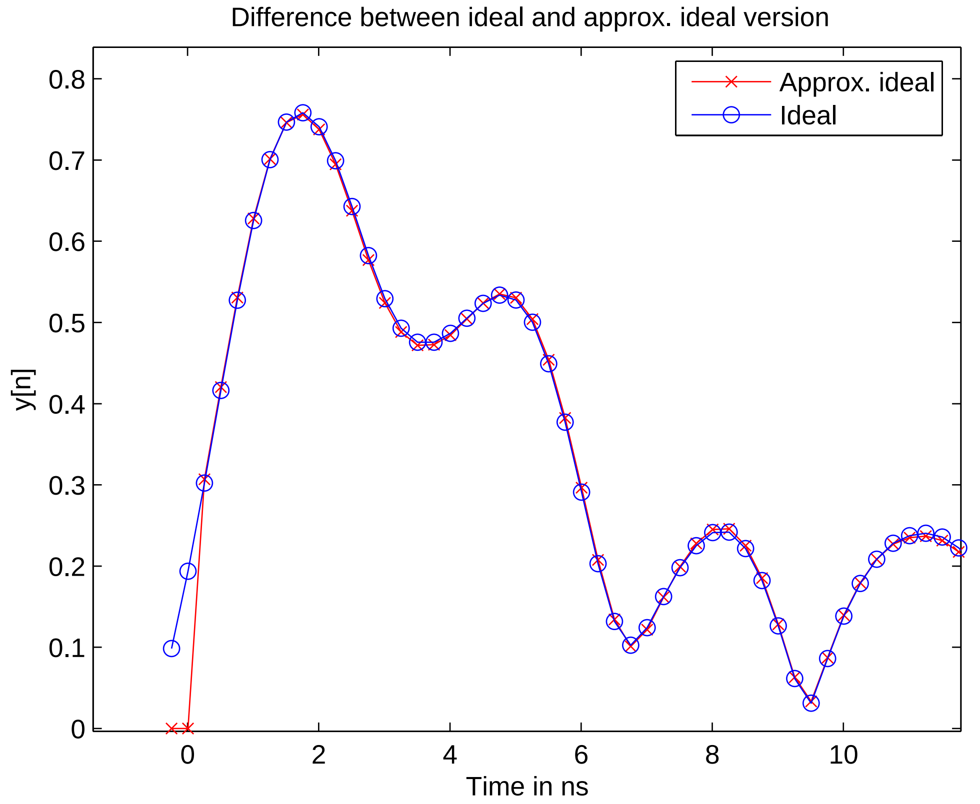


Figure 2: Comparing the ideal approach to its approximation