TESTING OFDM-BASED POSITIONING USING THE DIGITAL TV SIGNALS

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ABSTRACT

Recent regulatory incentives (E911) and numerous location-based services and applications currently require accurate urban and indoor positioning, which are challenging environments for Global Navigation Satellite Systems. This article investigates a means for enhancing positioning through the use of signals-of-opportunity based on the orthogonal frequency division multiplexing modulation. The use of digital video broadcast-terrestrial signals to develop and test a pseudorange estimation method employing real signals is presented. The test bench to do so is thoroughly presented. The first testing results with real signals are then investigated in an urban environment showing a potential accuracy of about 11 meters RMS with a mean bias on the order of 9 meters.

Index Terms — OFDM, DVB-T, Signal-of-Opportunity, positioning, navigation

1. INTRODUCTION

Because of recent regulatory incentives (E911) and development of numerous location-based services (LBS) and applications, urban and indoor positioning currently represents a significant market. However, these environments are well-known for the challenges they raise for GNSS systems because of signal blockage, multipath, interference, and other factors. Even if specific GNSS signal processing techniques have been developed to address these issues (e.g., high-sensitivity receivers, assisted-GNSS techniques, system upgrades), they only provide limited position availability, accuracy, and continuity indoors and in urban settings.

Some alternatives exist to complement GNSS in such environments. These include other navigation sensors (such as inertial sensors, magnetometers, odometers, lasers, and video), dedicated radio-location systems (pseudolites, RFID, UWB) or signals-of-opportunity (SoOs).

SoOs are communication signals such as those broadcast by mobile telephony, TV, radio, or Wi-Fi operations that can also be exploited for positioning. Even if they are not meant for positioning, they have the advantage of availability and diversity in urban and indoor environments and permit, by definition, good integration of the communication and positioning services.

Among the various communication signals that could be used as SoO, this article focuses on signals based on the Orthogonal Frequency Division Multiplexing (OFDM) modulation. OFDM appears to be a good candidate to provide a positioning service in light of increasing interest in this modulation for communication and broadcasting of actual and future signals.

From the variety of OFDM-based standards, the European standard for digital television, the digital video broadcasting – terrestrial (DVB-T) standard has been investigated by the authors because it is already used and thus allows real signal testing. This article reports on the processing of real DVB-T signals for ranging purpose, and is based on techniques previously developed by the authors [2;3;4;5]. In particular, this article stresses the design of the test bench to process real signals and the methodology to assess the ranging techniques previously developed by the authors.

The outline of this article is thus the following: in section 2, the DVB-T standard is introduced; in section 3, the authors' pseudorange estimation technique for terrestrial OFDM-based networks is presented; in section 4, the test bench to collect real signals and obtain a reference trajectory is presented; in section 5, results in an urban environment are provided and analyzed; finally section 6 concludes this paper and introduces future work.

2. PRESENTATION OF THE DVB-T

This presentation of the DVB-T assumes a knowledge on OFDM. For more details on OFDM, please refer to [1;7].

2.1 General DVB-T Parameters

The DVB-T [6] is a European standard for digital TV broadcasting to fixed receivers in the VHF and UHF bands and is based on OFDM modulation. This standard defines several modes which depend on three parameters: the FFT size (N), the ratio between the Cyclic Prefix length and the useful OFDM symbol length ($CP = N_{CP}/N$) and the sampling period (T_{samp}). More “commercial” terms are derived from the FFT size N and the sampling period T_{samp}.

They are the transmission mode equivalent to the FFT size and the approximate bandwidth equivalent to the sampling period. Their values are given in Table 1 For all the possible modes, CP can take any of the following values: 1/32, 1/16, 1/8, 1/4.

Table 1: DVB-T Transmission Mode

FFT size	Transmission mode	Sampling Period (µs)	Approximate bandwidth
1024	1K	7/64	8MHz
2048	2K	1/8	7MHz
4096	4K	7/48	6MHz
8192	8K	7/40	5MHz

2.2 DVB-T Subcarrier Types

The N subcarriers of an OFDM symbols have different natures. They are:

Null subcarriers:

Null subcarriers are situated on the edges of the signal spectrum and have a zero value. They serve as guard bands to avoid out-of-band emissions of the OFDM signal.

Data subcarriers:

Data subcarriers carry the useful information. In the case of DVB-T, the useful information is the TV broadcast (MPEG-2 multiplex) interleaved and coded to improve its robustness. The data bits are mapped on 7 possible constellations.

Transmission Parameter Signaling (TPS) subcarriers:

TPS subcarriers carry information about the transmission such as data constellation map, code rates, transmission mode, CP length…

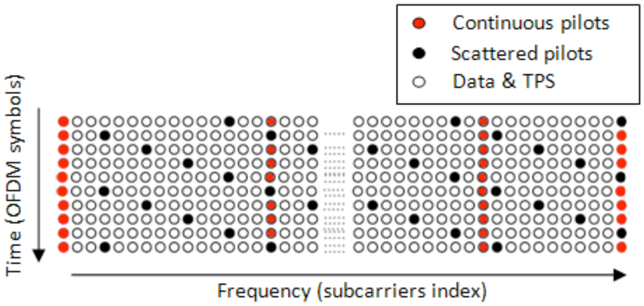

Figure 1 - Location of the Scattered and Continuous Pilots on a DVB-T Signal

Pilot subcarriers (Figure 1):

Pilot subcarriers have values known by the receiver and are useful for several synchronization processes necessary to demodulate correctly an OFDM symbol. The pilot subcarriers are BPSK-modulated and are transmitted with a an amplitude boosted by a 4/3 factor. The pilot subcarriers are multiplexed with a Pseudo-Random Binary Sequence (PRBS). The pilot index set is decomposed in 2 subsets:

- **Scattered pilot** set, in which pilots are evenly spaced but whose positions differ from an OFDM symbol to another but repeats every 4 OFDM symbols.
- **Continuous pilot** set, in which pilots are at a fix position from an OFDM symbol to another (their position is defined in the standard).

In France, where the real signals' tests were done, the DVB-T is the standard chosen by the authorities for the national terrestrial digital television. The parameter for the French DVB-T are presented in Table 2. The two possible types of network, Multi-Frequency Network (MFN) and Single-Frequency Network (SFN) are available in France.

Table 2: DVB-T Parameters in France

Mode – FFT size	8K - 8192
Approximate bandwidth – Sampling period	8MHz – 7/64 µs
CP ratio	1/8
Data symbols constellation	64-QAM
Possible central frequencies in UHF band (MHz)	$474 + (k-21) * 8 + f_{\text{offset}}$

where:

- $k \in \{21, \dots, 69\}$ is the channel number
- $f_{\text{offset}} = 166.667$ kHz a spectrum protection offset

3. DESCRIPTION OF DVB-T PSEUDORANGE ESTIMATION METHOD

The techniques developed by the authors to obtain pseudorange measurements were presented in details in [5;2;3;4]. Only a brief summary is provided here.

The method is based on the computation of a classical correlation between the known part of the received signal (pilot components) and a local replica of this same known signal generated by the receiver. The resulting correlation function can easily be shown to be a sinc function. This correlation output can then be used for both acquisition and tracking. The width of the main lobe of the correlation function is approximately 80 meters for the French DVB-T.

The standard deviation of the delay tracking error using this technique was derived theoretically and validated through simulations described in [3] for an ideal Additive White Gaussian Noise (AWGN) channel. This earlier study showed that the proposed DVB-T tracking technique has a tracking threshold about 30 to 40 dBs below the DVB-T demodulation threshold and a ranging accuracy at the decimeter level for a signal-to-noise ratio (SNR) around -15 dBs. This clearly indicated that even when strong fading occurs, a good chance exists that the signal can still be used for ranging.

Due to the specificities of the terrestrial propagation channel, it was anticipated that multiple peaks corresponding to all the replicas of the transmitted signal reaching the receiver would appear in the correlation function obtained from real signals. More notably, the peak corresponding to the first received signal (the one of interest for ranging) is not necessarily the most powerful and might not even be present. In order to try to always track the shortest signal (either the direct signal or, by default, one of the shortest replicas), the proposed ranging method uses multiple Delay Lock Loops (DLL) in order to constantly track several correlation peaks. This allows relying on the second shortest tracked replica if the first one disappears due to fading or signal blockage. The following method is then used:

- First, an iterative algorithm is used to acquire the delays corresponding to the different peaks of the correlation function (ESPRIT [9] or Matching Pursuit [8]). To make sure that the direct signal or the shortest detectable replica is not missed the acquisition is run periodically.
- Second, all (or a subset of all) the acquired peaks are tracked independently using several DLLs. The shortest tracked delay is then used to form the pseudorange measurement. Specific detectors are used to minimize the number of replicas tracked.

Note that the propagation channel can lead to significant impairments due to the near-far effect, particularly in SFNs. To mitigate this, we can use windowing techniques in order to reduce the correlation side-lobes. Rectangular, Hamming and Blackman-Harris windows were tested with this regards when considering ranging techniques in a SFN [Thevenon, 2009]. It was shown that the Hamming and Blackman-Harris were very helpful in this case for the acquisition of the signals received from different emitters.

4. PRESENTATION OF THE TEST BENCH

4.1 Presentation of the Test Bench

The test bench is composed of a hardware part and two pieces of software.

The hardware part (Figure 2) allows receiving and digitizing the TV signals from two independent TV antennas. A GPS receiver provides time references for the rest of the hardware and permit to have a reference position. This test bench has been designed to be very flexible and the two reception chains allow the following test configurations:

- Two TV antennas receiving the same signal to exploit antenna diversity.
- Two TV antennas receiving two signals at two frequencies to exploit frequency diversity.
- Two TV antennas receiving two signals at two frequencies from two emitters
- One fixed antenna and one mobile antenna to perform differential measurements.

The signal recording software is used to configure and control the hardware and to collect and save on the computer hard drive the digitized TV signal.

The signal processing software implements the pseudorange estimation method to process the recorded signal.

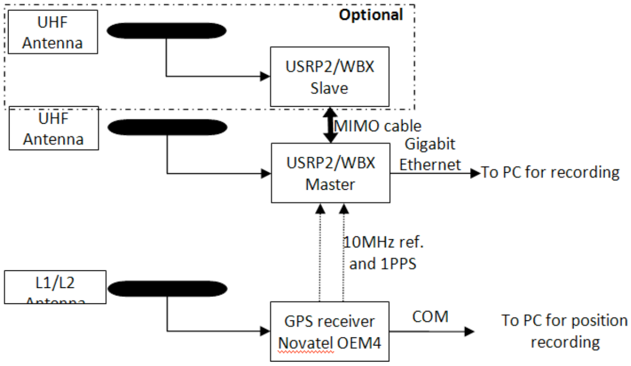

Figure 2 - Architecture of the Test Bench

Antennas

The two TV antennas are (1) a mass-market amplified mobile omni-directional UHF antenna ELAP – 40 dB gain, 1.1 dB noise factor (vendor information), (2) a mass-market amplified indoor omnidirectional UHF antenna Meliconi Ad-elegance – 20 dB gain, 3.5 dB noise factor (vendor information).

USRP2/WBX Devices

The USRP2, build by Ettus Research LLC, is a low-cost, flexible and open-source radio device, controlled by PC, that permits to receive and transmit simultaneously on two antennas a limitless variety of signals.

In the presented test bench, only the reception chain of two USPR2 is used and the chosen daughterboard permits to receive signal between 50 MHz and 2.2 GHz with a bandwidth up to 30 MHz.

The two USRP2 are used in a Master/Slave configuration. The Master USRP2, locked to the GPS time thanks to the 10 MHz and 1 Pulse-Per-Second (PPS) signal of the GPS receiver, is connected to the host PC through the gigabit Ethernet interface. The Slave USRP2 is connected to the Master with a MIMO cable, to have the same timing as the Master (thus also locked to GPS time). In addition, the digitized signal of the Slave USRP2 passes through the host PC through the gigabit Ethernet interface in the same time as the digitized signal of the Master USRP2.

GPS Receiver

The GPS receiver, a NovAtel OEM4 ProPak-G2, is used for two purposes:

- Record on the host PC the position computed by the receiver every second
- Provide to the Master USRP2, the 10 MHz and 1PPS signal. On this receiver, the internal clock is steered on the computed GPS time. It has however to be kept in mind that the 10 MHz and 1PPS output have some limitations in their accuracy, since they both depend on the quality of the received GPS signals. Under correct reception conditions it is evaluated that the standard deviation of computed GPS time error is around 5 to 10 meters.

4.2 Validation of the Test Bench

Clock Error-Free Pseudorange Measurement

To quantify the performance of the Pseudorange estimation method on real signals, it is essential to be able to have a PR measurement independent from the transmitter/receiver clock drift. To obtain this clock error-free PR measurement, several solutions are possible. In the present case, it was decided to exploit the fact that some digital TV emitters should be synchronized to GPS time. Based on the knowledge that the USRP2 should be locked on GPS time as seen earlier, it was assumed feasible to get clock-error free PR measurement.

The test bench presented on Figure 2 was used with only one USRP2 to record the TV signals from the three TV emitters around Toulouse, France. Among these emitters only one seemed to be synchronized with GPS time. Indeed for this emitter the estimated delay varies in a span of only ±2 meters over 300 seconds. This variation can be due to two factors: low SNR of the received TV signal (about -5 dB) and emitter and receiver clocks not perfectly steered on GPS time. However, this variation was deemed appropriate regarding the targeted precision.

From Received Time to Absolute Range Computation

To quantify the performance of the tracking method, the estimated pseudorange has to be compared to the true range between emitter and receiver. This true range can be easily obtained since the emitter position is known (precision of about one meter) and the receiver position is recorded by the GPS receiver that is part of the test bench. However, it has to be kept in mind that the proposed software can only provide an estimation of the time of reception of the received signal based on the receiver internal clock. This could be translated into a range if the instant of generation of the transmitted signal was known.

This instant of emission was determined by recording and processing a TV signal coming from the considered emitter. The receiver was placed at a known location and in direct sight of the emitter such that the error on the estimated delay due to multipath was as small as possible. Knowing the GPS time of the signal's reception and the exact distance between the emitter and the receiver, it is possible to extrapolate the instant of emission of the OFDM symbol. Based on this, and assuming that the emitter was indeed locked onto GPS time, it is then possible to generate absolute range estimation based on the receiver's estimated received time for any subsequent test. Such calibration was repeated 10 times to average the result. The confidence in the resulting calibration is quite good since the standard deviation of the resulting set of 10 values is about 1.7 meters.

5. LIVE SIGNALS' TESTS

5.1 Test Description

The dual antenna version of the test bench is used in this test. The distance between the TV emitter and the test zone is about 80 km. The TV emitter is also a geodetic reference point whose global coordinates are precisely known. This emitter has an antenna height of 89 m, an ERP of 8kW, and the carrier frequency of the signal is 762,166667 MHz. Figure 3 shows one of the 5 trajectories of the car during the tests. In this example, the route length is about 2 kilometers and the travel duration is 5 minutes.

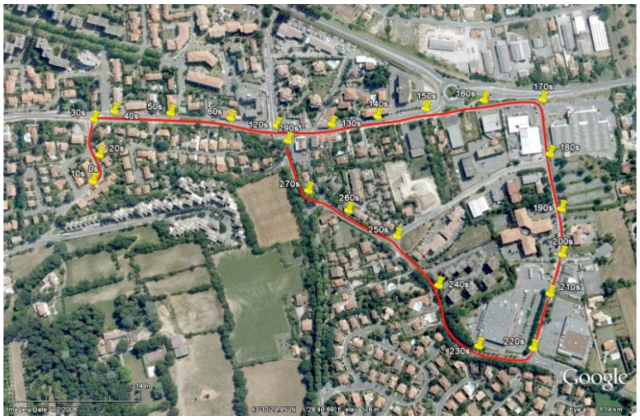

Figure 3: Car Trajectory During the Test

5.2 Results

During the processing, the correlation computation is done with the Hamming window. The correlation duration in the DLL is equal to one OFDM symbol. The delays' tracking block uses a second order loop with a bandwidth of 1 Hz. The DLL correlator spacing is set to 1 sample. Ten peaks are acquired and tracked and no reacquisition is done.

Only one of the 5 trajectories (the one introduced in section 5.1) is analyzed here (it is representative of the other ones).

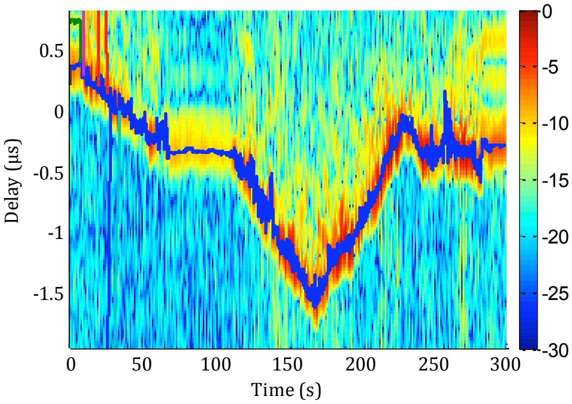

Figure 4: Correlation image and estimated delays

Figure 4 shows the correlation image, representing the evolution of the amplitude of the absolute value of the correlation function over the 300 seconds of the test. Each correlation function is computed on a delay range of ±200 samples around the first path estimated during the acquisition. The color code represents the amplitude relative to the most powerful received signal. The estimated delays are superimposed on the correlation image.

It can be seen on Figure 4 that a correlation peak clearly emerges from the noise by about 20 dB during the whole simulation. However it can also be seen that this peak is very unstable mainly due to intense multipath in this urban environment when the receiver is moving. A stabilization appears only in the three static phase. This instability has a clear impact on the estimated delay.

Figure 5 shows the difference between these estimated pseudoranges and the reference pseudoranges, referred to as the tracking error. One can observe that the estimated pseudoranges from antenna #1 and antenna #2, less than one meter apart, are very different (up to 100 meters of difference). This is not so surprising considering the very dense multipath environment in which the vehicle is driven. In addition, the estimated pseudorange, even if quite stable in static phase, is very disturbed in dynamic phases, with a tracking error increasing by up to 100 meters in less than one second. Furthermore, it can be seen that the tracking error is mostly positive. This observation is representative of the so-called non-line-of-sight (NLOS) error, which can be explained by the presence of delayed multipath that can be more powerful than the direct signal.

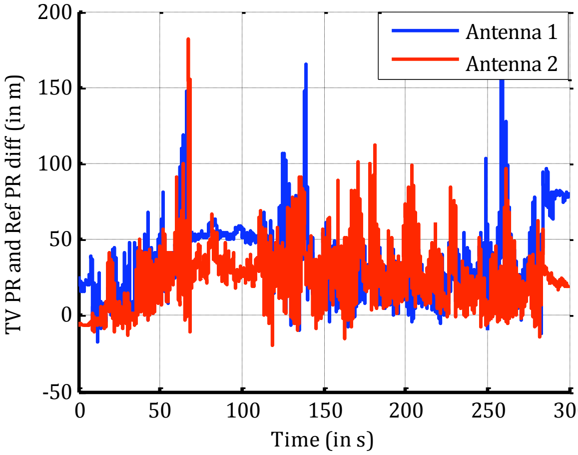

Figure 5: Tracking Error for the Two Antennas

In the present analysis, the static phases are discarded as they represent a fixed configuration. Looking at the set of 5 test trajectories, the mean tracking error obtained from both antennas during dynamic phases was about 39 meters and the standard deviation of this error was around 30 meters. An advanced measurement processing technique to reduce the NLOS error was also tested, providing a significant improvement: the mean tracking error was about 11 meters and the standard deviation of this error was around 9 meters. Other tests, not shown in this paper, were also performed indoors. They showed the possibility of tracking the DVB-T signal where GNSS is usually completely unavailable.

Tests in a SFN network were also performed in sub-urban and urban environments. The results are again very promising with a standard deviation of the Time-Difference Of Arrival (TDOA) error of about 5 meters in the sub-urban case and 16 meters in the urban case.

6. CONCLUSIONS

A flexible test bench, allowing TV signal recording on two reception chains, synchronized of GPS time and providing a reference position has been developed. A complete C++ software has also been developed to control the hardware and process the recording signal according to the developed ranging method.

Tests in urban area using two reception antennas and a DVB-T emitter synchronized on GPS time could be realized. The tracking performance is quite good and promising with a mean error of about 30 meters and a standard deviation of about 20 meters. The tracking performance can be improved using an advanced measurement processing technique to a mean error around 11 meters and a standard deviation around 9 meters.

7. REFERENCES

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