Experimental UWB Channel Characterization on Fire Scenarios in Confined Environments

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Abstract

Firefighters should face to different situations during fire extinction. Usually, they demand sensing and location applications to improve its safety, particularly for confined environments. UWB communications have been widely investigated for high resolution positioning and sensing applications due to its unique characteristics. In this work, the effect of fire and combustion on UWB propagation inside a metallic container is investigated. Initial results shows that temperature does not affect the UWB path loss while this parameter improve at the end of the fire due to the reduction of combustion materials.

1. Introduction

Ultra-Wideband (UWB) signals are defined as those whose bandwidth is larger than 500 MHz (UWB with a large absolute bandwidth) and/or larger than 20% of the central frequency (UWB with a large relative bandwidth). UWB communications have focused the interest in the research community due to its large bandwidths, high precision, low consumption and high data rates [1]. Due to these attractive characteristics the main application fields for UWB communications are precise indoor location and sensing, radar systems or Personal and Body Area Networks (PAN and BAN) [2], [3].

Fire detection and extinction in indoor and confined scenarios requires a precise location and sensing to assure the safety of firefighters and other personal. It was shown in [4] and [5] that the presence of fire, high temperatures and combustion gases can modify propagation conditions for UHF and VHF bands. In [6], authors obtain that the complex permittivity in the combustion zone vary due to fire and combustion in open environments for the 8- 9.6 GHz frequency band. However, to the best of the authors' knowledge, there is no information about the influence of fire and combustion on UWB propagation.

This work presents initial results of an UWB measurement campaign inside a metallic container where a fire was reproduced. The paper is organized as follows: Section 2 describes the environment were measurements took place and the experimental setup and Section 3 presents the results of the UWB propagation characteristics during the experiment. Finally, Section 4 presents the conclusions of this work.

2. Environment and Measurement Procedure

2.1 Measurement Environment

Measurements were undertaken in a metallic 40-feet long standard metallic container whose dimensions are 12.19 (long) x 2.44 (wide) x 2.6 (height) meters. This container have several doors to control the input of air inside as shown in Figure 1. Furthermore, four thermocouples (green circles at Figure 1) were installed at a height of 1.0, 1.5, 2.0 and 2.2 meters over the floor in order to register the temperature inside the container during measurements.

One antenna was placed at both sides of the container, just outside the doors frame in order to protect them from high temperatures. Both antennas were located in line of sight at 1 meter over the floor in Line-of-Sight (LoS) at a distance between them of 12.2 meters.

The fire was caused by combustion of wood and similar materials that were installed 4 meters far from one side of the container and obstructing the LoS of the direct path as it is depicted in Figure 1.

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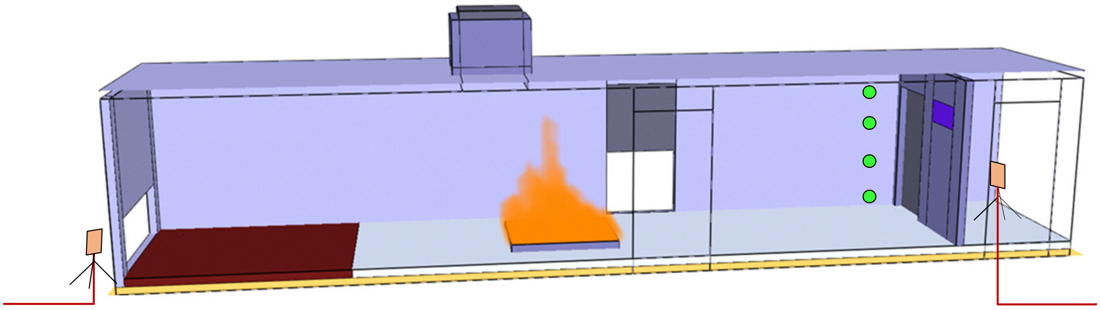

Figure 1. Experimental setup.

2.2 Channel Sounder and Measurement Procedure

The channel sounder used to perform the measurements is based on the Agilent ENA E5072A vector network analyzer (VNA), which can measures the S_{21} parameter up to 8.5 GHz. Transmitting and receiving antennas are connected to the VNA ports by using two 20-meter long coaxial cables as shown in Figure 1. The measurement system (VNA, coaxial cables, and connectors) is calibrated before sounding the channel in order to remove the frequency response of all elements from the measurements.

For the measurements, we have two planar omnidirectional antennas which work in the 3–10 GHz frequency band. The power transmitted by each antenna was -10 dBm, and the dynamic range was 96 dB, which was enough to assure a high signal-to-noise ratio (SNR) for most of the measurements. Thus, the noise power was -106 dBm measured within a bandwidth of 3 kHz.

However, due to the frequency limitations of the VNA and UWB antennas, the radio channel can be measured between 3 GHz and 8.5 GHz. The maximum number of frequency points of the VNA is 1601 points so the channel has been sounded with a frequency resolution of Δf= 3.4375 MHz.

The UWB channel was measured every 10 seconds during the experiment while the thermocouples monitor the temperature every second. In order to emulate the conditions that take place in real fires, four phases can be distinguished:

1. Phase 1 begins with the ignition and continues with a maintained increase in temperature due to the fire
2. In Phase 2 the container lateral doors (see Figure 1) are opened in order to increase the air inside the container and thus, continue increasing the fire and temperature.
3. Phase 3 starts closing again the doors with the aim to increase the combustion gases inside the container.
4. In Phase 4 begins the extinction with water until the disappearance of fire.

It should be mentioned that measurements before start the experiment were undertaken in order to compare the results obtained in case of UWB signals are propagated though the fire with the propagation in absence of fire.

Summarizing, corresponding to each instant during the experiment, t_k, we have the channel transfer function **H**(f) with f=1601 frequency points for a certain temperature during the experiment.

3. Results

The evolution of temperature inside the container during the experiment is presented in Figure 2 for the lowest and the highest thermocouples. It can be observed how during Phase 1 and Phase 2 temperature increases. During Phase 3 the fire starts to be reduced and temperature decreases. This decrement of temperature is more noticeable in Phase 4 due to the introduction of water to extinct the fire.

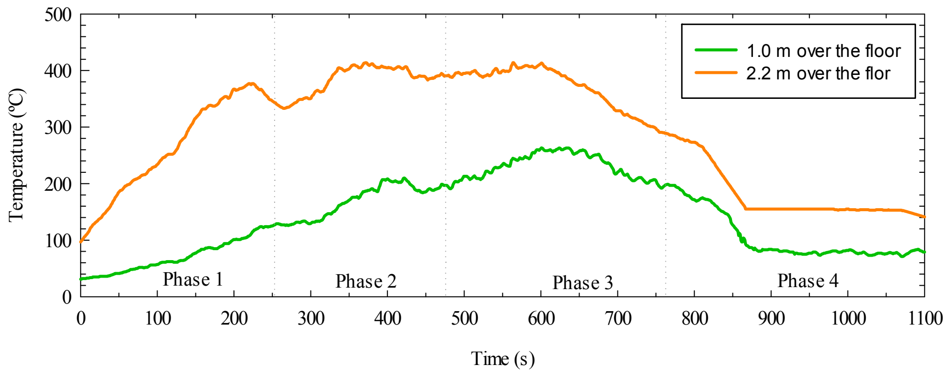

Figure 2. Temperature inside the container during the experiment.

Next, we present results of the evolution of the measured path loss during the experiment, since for a constant transmitted power it is a direct measure of the received power. The path loss is defined as the ratio of the transmitted power and a local average of the received power and can be obtained from the power delay profile (PDP). Thus, The $PDP(\tau)$ at a certain time during the experiment t_k is computed as:

$$PDP_{t_k}(\tau) = |h(\tau)|^2 \tag{1}$$

where $h(\tau)$ is the channel impulse response obtained from the Inverse Fast Fourier Transform (IFFT) of the 1601-point frequency response, $\mathbf{H}(f)$.

Thus, the mean path loss in logarithmic units is calculated from the PDP as:

$$L_{t_k} = -10\log_{10}\sum_{i=0}^{N_f} PDP_{t_k}(\tau_i) \tag{2}$$

where N_f is the number of points of the *PDP*. A threshold of 20 dB under the maximum of the PDP has also been set in order to remove the noise [7]. The measured path loss during the experiment, L_{t_k}, has been referred to the path loss measured before ignition, L_0, as:

$$L = L_{t_k} - L_0 \tag{3}$$

Figure 3 presents the relative path loss measured during the experiment. It can be observed how temperature does not affect the path loss. However, at the beginning of path loss the relative path loss begins to decrease, i. e. the measured path loss L_{t_k} decreases, and thus, the received power increases. This effect is due to the reduction of the combustion material size which obstructs the direct path. The same effect was found in [4].

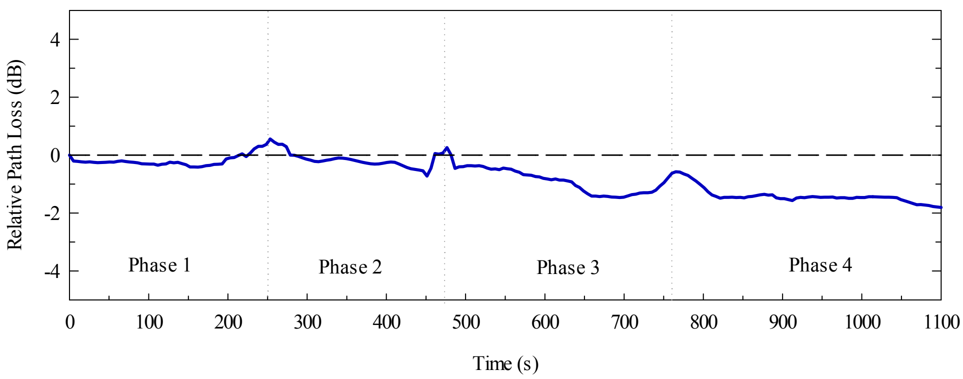

Figure 3. Relative path loss as a function of time during the experiment.

Next, we wanted to investigate the influence of the UWB bandwidth in the relative path loss during the experiment. To accomplish this, 500 MHz, 1 GHz, 2 GHz, 3 GHz, 4 GHz and 5 GHz bandwidths have been considered maintaining the central frequency of the frequency band under measurement, f_c=5.75 GHz. It should be taken into account that for each bandwidth the measured path loss has been referred to that in such bandwidth at instant t_k=0. Figure 4 shows how for all bandwidths the path loss exhibits the same behavior than in Figure 3 for the whole bandwidth, decreasing only with the decrement of the materials that obstructs the direct path.

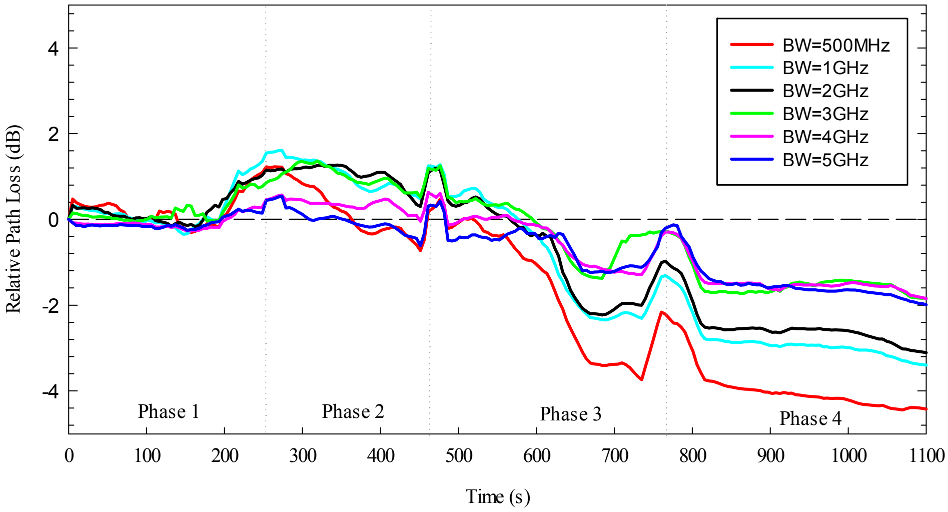

Figure 4. Measured path loss as a function of time during the experiment for different bandwidths.

However, Figure 4 also shows how this improvement in the measured path loss in phases 3 and 4 (decrement in the relative path loss) is more noticeable for smaller bandwidths. At the end of the experiment, when the fire is nearly extinct the measured and there is water vapor within the container, the path los for a bandwidth of 500 MHz is 2.5 dB higher than for BW=3GHz case due to the same phenomenon.

4. Conclusion

In this paper, initial results of a UWB measurement campaign in case of fire have been outlined. Measurements were carried out in a 40-feet metallic container were fire and environmental conditions were reproduced. Results shows that the temperature does not have a significant impact in UWB propagation. Moreover, it was observed how as the size of the combustion materials decreases, the path loss decreases especially for small UWB bandwidths. However, further investigations and experiments are needed in order to improve the understanding of UWB propagation in these particular environments.

5. References

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