NLOS Influence on 60 GHz Indoor Localization Based on a New TDOA Extraction Approach

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Abstract— **In the field of 60 GHz high data rate wireless communications a new method for indoor localization at 60 GHz is proposed. This method is based on the extraction of the TDOA (Time Difference of Arrival), using a MISO system. With this method, unlike conventional TDOA measurements, it is possible to perform communication and localization at the same time by transmitting two identical UWB OFDM signals using two antennas at the TX and extracting TDOA from the interference spectrum of these two signals at the RX. TDOA. In addition, The NLOS (Non line of sight) influence on the TDOA and the localization precision is investigated for different cases. This whole study is made within the framework of the WiGig alliance specifications.**

Keywords— Indoor localisation, millimeter wave communication, 60 GHz communication, OFDM, TDOA, NLOS, ultra wideband communication, wireless networks.

I. INTRODUCTION

In the coming years, home wireless systems are expected to provide multi gigabit data rates, thus replacing cables for indoor communications. [1] Wideband communications using complex modulations such as OFDM (Orthogonal Frequency Division Multiplexing) are more and more used in the short-range applications such as video streaming, wireless USB ... However, the current commercial wireless systems do not still reach the necessary data rate for heavy applications like HD video. So, an effort exists to develop a wireless UWB (Ultra Wide Band) technology at 60 GHz, where 5 GHz bandwidth is available internationally [2]. In this context, IEEE 802.15.3c standard was already proposed, whereas other specifications, for example WiGig, are being elaborated [3], [4].

Furthermore, energy consumption in wireless networks is an essential factor with respect to its impact upon the environment as well as autonomy of the system. For 60 GHz communications, this is even more problematic than in conventional wireless networks because of the strong millimeter wave attenuation [5], [6]. Focalization of energy can lead to decrease the consumption and to improve the distance range of the wireless communications. This is why under development 60 GHz standards consider beamforming. However, to be able to focalize, the communicating devices should determine their locations. Localization plays an important role in achieving a precise, low consumption wireless communication, since it is the basis of routing algorithms in multi-nodes networks [7]. In this article, a new technique of localization for wideband wireless networks at 60 GHz adapted to indoor applications is presented. This method is based on conventional TDOA (Time Difference Of Arrival) measurements. However, it uses interferences in OFDM signal spectrum at RX in order to extract the TDOA. With this approach, we are capable of performing localization and the data transmission simultaneously. First, this new approach is developed simply for a LOS (Line of sight) case, then the NLOS (Non line of sight) influence on the TDOA extraction is explored considering different scenarios.

The paper is organized as follows. In section 2, theory, concepts and formulations are presented. In section 3, a simulation example is given. Finally, the section 4 will conclude the paper.

II. CONCEPT AND FORMULATIONS

The method of localization proposed in this article is based on extracting TDOA from interferences between the OFDM signals transmitted by two antennas at 60 GHz [8], [9]. To implement this technique, a MISO (Multi Input, Single Output) structure is considered. To do so, a reference device (RD) with two antennas A_1 and A_2 and a mobile device (MD) are placed in an indoor environment. The distance between MD and A_1 is d_1 and between MD and A_2 is d_2. In the case of LOS (Line Of Sight) between RD and MD, the delays of propagation are $\tau_1 = d_1/c$ and $\tau_2 = d_2/c$, with c the speed of light and h_1 and h_2 the channel gains respectively between A_1 and MD and between A_2 and MD. A_1 and A_2 transmit the same OFDM 60 GHz signals with a sample rate frequency f_s, N carriers and M data carriers. Furthermore, the delay τ_p is considered, as it has been suggested in [10], to vary the delay of the signal in a predetermined way. Considering x(t) the modulated baseband signal transmitted by both antennas, the following equation is obtained:

$$x_1(t) = x(t) = \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} c_k e^{\frac{i2\pi k F_s t}{N}} e^{i2\pi F_{RF} t} = \sum_{k=-\frac{M}{2}}^{\frac{M}{2}-1} c_k e^{\frac{i2\pi k F_s t}{N}} e^{i2\pi F_{RF} t} \quad (1)$$

$$x_2(t) = Ax(t - \tau_p) \quad (2)$$

Where A is a real constant, c_k are complex coefficients, with k the carrier index and F_{RF} the RF frequency. The MD receives:

$$y(t) = h_1 x(t - \tau_1) + h_2 A x(t - \tau_p - \tau_2) \qquad (3)$$

In the case $h_1 = A h_2$, the received signal can be written as:

$$y(t) = h_1[x(t) + x(t - \tau)] \qquad (4)$$

Where $\tau = \tau_p + \tau_2 - \tau_1$. The signal received in the frequency domain can be presented as follows:

$$Y(f) = H_1 \sum_{k=-\frac{M}{2}}^{\frac{M}{2}-1} c_k \delta\left(f - \frac{kF_S}{N} - F_{RF}\right) * \left(1 + e^{-i2\pi\tau\left(\frac{kF_S}{N}\right)+F_{RF}}\right) \qquad (5)$$

Each pair of carriers $|k|$ is canceled for values of τ given by:

$$\tau = \frac{nN}{2|k|F_S + 2NF_{RF}} \quad n = 0,1,2,\dots \qquad (6)$$

Considering only the baseband signal, (6) can be simplified to:

$$\tau = \frac{2n+1}{2|k|F_S/N} \quad n = 0,1,2,\dots \qquad (7)$$

Equation (7) shows that TDOA can be obtained by observing the specctrum of recieved signal and by measuring the frequency difference between two nulls (in practice, minimum received power). For the NLOS case, the theory and all the formulations are similar but due to the NLOS paths, the TDOA is calculated with some error. This NLOS influence is investigated in the next section.

III. SIMULATION AND SYSTEM DESCRIPTION

A. Case of LOS

To demonstrate the feasibility of our approach, a 60 GHz communication system is simulated using SystemVue software. The OFDM parameters are fixed according to the standard IEEE 802.15.3c (we would like to underline that the IEEE 802.15.3c specifications are almost identical to WiGig ones [11]). We thus consider f_s = 2,64 GHz, N = 512 and M = 354. To ensure the cancellation of a single pair of carriers, the values of τ which gives a unique solution for (7) are chosen. Knowing the values of TDOA that can be measured with our OFDM signal, a possible configuration is proposed in Fig. 1, in which a pair of antennas distant by 40 cm from each other performs the localization of a MD in a room. For this configuration, the reference device is chosen with A_1 and A_2 distant by 40 cm (B=40 cm) supposing that A_1 transmits the same signal as A_2 with a delay τ_p. The value of τ_p can be chosen to measure $\tau_2 - \tau_1$ with the maximum of dynamic range. The distance between RD antennas is chosen to observe the cancellation of a single pair of carriers. In Fig. 1, one possible configuration is represented with B the baseline distance, H horizontal distance between RD and MD and θ the angle of MD from baseline center.
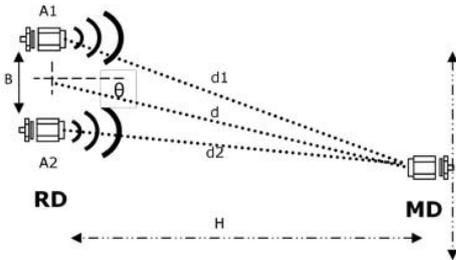

Fig. 1. RD and MD configuration.

A simulation example of a MD localization with this method is implemented by using the SystemVue and VSA 89600 software. For a fixed point in the room, for example for a 40 cm baseline and a MD which is located 2 m apart from RD (H=1 m, θ = 60° in figure (1)), the theoretical value of $\tau = \tau_p + \tau_2 - \tau_1$ for a LOS propagation between the RD antennas and the fixed point is calculated. τ =1.1 ns is obtained and thus according to (7), $|k|$ = 85 is expected due to the theory. The result obtained by the simulation confirms the value calculated by the theory.

Fig. 2, Fig. 3 and Fig. 4 present respectively the constellation, the spectrum and the EVM (Error vector magnitude) of the received signal which leads to detect the nulls (the cancellation is presented in $|k|$ = 85 as expected). This technique is promising as the localization data is carried by the null sub-carriers, thereby easily available in the base-band processing. As shown in Fig. 2, the constellation at the RX presents a high quality communication in the LOS case. However, it is shown in Fig. 3, that the spectrum of the signal is totally deformed and the position of nulls leads us to obtain the TDOA. A precise calculation of TDOA can be done by looking at the EVM of received signal, as shown in Fig. 4.
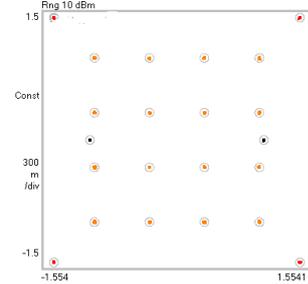

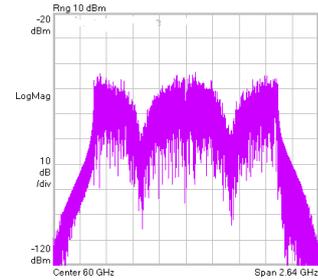Fig. 2. Constellation of received signal in LOS scenario.

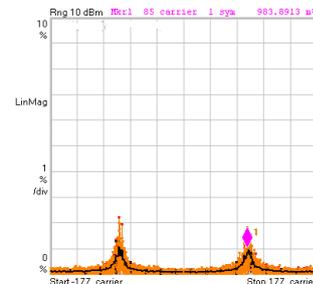Fig. 3. Spectrum of received signal in LOS scenario.

Fig. 4. EVM of received signal in LOS scenario.

B. Case of NLOS

The same simulation example is implemented for different NLOS cases. As shown in Fig. 5, For each case, one NLOS scenario is added to the configuration of the LOS case.
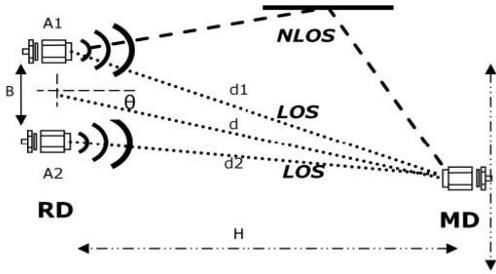

Fig. 5. RD and MD configuration in NLOS Scenario.

The calculated TDOA value is not anymore the same as the theoretical expected value due to the NLOS influence on the received signal spectrum. For the same configuration of RD and MD different NLOS paths are studied. The maximum coherence bandwidth at 60 GHz for the indoor environment is about 50 MHz [12]. So the maximum delay spread is about 20 nsec. Here, the case corresponding to a NLOS which is 300 cm (10 nsec) is presented to study even a worse case with a bigger error. According to (7), $|\mathbf{k}| = 85$ is expected due to the theory but The result obtained by the simulation does not confirm this value since the NLOS contribution affects the position of the nulls in the spectrum and changes the position of the maximum EVM. In this case the peak of EVM is at $|\mathbf{k}| = 71$, so the TDOA error is 16.5%. Fig. 6, Fig. 7 and Fig. 8 present respectively the constellation, the spectrum and the EVM (Error vector magnitude) of the received signal of this NLOS case. As shown in Fig. 6, the constellation at the RX presents a worse communication in the NLOS case than the LOS case. It is been shown in Fig. 7, that the spectrum of the signal is totally deformed and the position of nulls changed, which affects the determination of the TDOA. As shown in Fig. 8, the maximum EVM of received signal is not the same as the case of LOS.
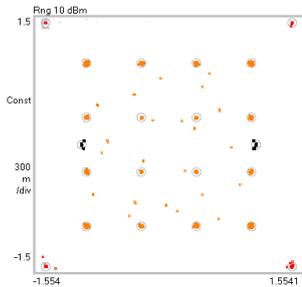

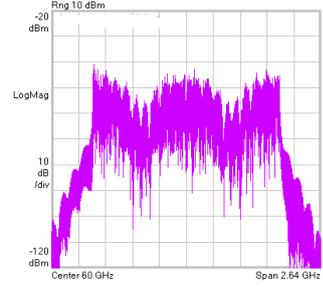Fig. 6. Constellation of received signal in NLOS scenario.

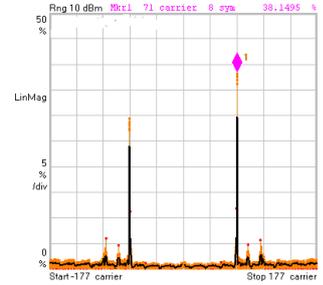Fig. 7. Spectrum of received signal in NLOS scenario.

Fig. 8. EVM of received signal in NLOS scenario.

C. Influence of NLOS on TDOA error

To demonstrate the influence of NLOS on TDOA error, different cases are studied. The worst cases are the values of NLOS which are close to theoretical TDOA which is 1.1 nsec for this configuration. If the chosen NLOS path is not close to theoretical TDOA, it means that this path is too much longer than the LOS path, Thus, it's effect on the TDOA is negligible due to free space attenuation So a range of NLOS paths which add 40 cm to 3 m to the LOS path are chosen. The delay corresponding to these values vary from 1.3 nsec to 10 nsec. In figure 8, these different cases are presented. For each path the worst case, is the case in which just the power loss is only due to the free space attenuation. In Fig. 9, 0 dB corresponds to this case because of the normalization. All the other points for each path present different power losses due to absorption or reflection and they are all normalized. It is shown in figure 8 that for each path if the power loss due to the reflection and absorption is 12 dB more than the path loss itself, then the TDOA error is less than 5 percent. So the calculated TDOA, even in case of NLOS, is close to the theoretical value.
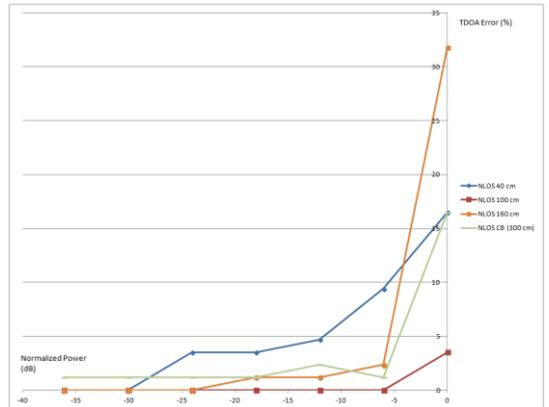

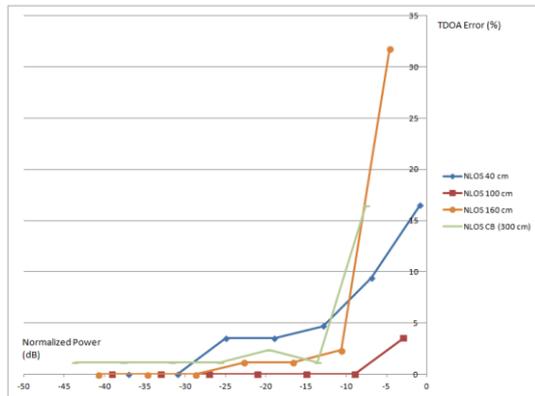Fig. 9. TDOA error for different NLOS Scenarios.

Fig. 10. TDOA error for different NLOS Scenarios.

In Fig. 10, the same scenarios but this time normalized to the LOS power loss are presented. It is shown in figure 9, that for each path if the power loss due to the reflection and absorption is 8 dB more than the LOS path loss, then the TDOA error is less than 5 percent.

IV. CONCLUSION

In this paper, a new method to extract the TDOA is presented. This method is particularly well-suited for 60 GHz communication systems that use UWB OFDM signals. It was shown that, in the hypothesis of LOS scenario and the use of two antennas at reference device (RD), it is possible to estimate a 1D or 2D position of a mobile device (MD) in a room. Besides, this technique, contrary to classical measurements of TDOA, has the advantage to perform localization and communication in a simultaneous way. Different NLOS scenarios are studied. The obtained results show that a TDOA error due to NLOS influence is less than 5% if the reflection and absorption power loss is more than 12 dB for the NLOS path.

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