Indoor positioning system based on the UWB technique

F.Elbahhar *, B.FALL *, M.Heddebaut*, A.Rivenq **, J.M.Rouvaen **

* IFSTTAR-LEOST Univ. Lille Nord de France, F-59000 Lille, France.
F-59666 Villeneuve d'Ascq, France fouzia.boukour@ifsttar.fr

** CNRS, UMR 8520, UVHC, IEMN-DOAE, F-59313 Valenciennes, France

***Abstract*— This paper explores the possibility to realise the indoor positioning system using the Ultra wide Band. The Ultra wide band technique allow a high precision ranging due to its fine resolution in order to resolve multipath fading and the presence of lower frequencies in the base band in order to penetrate walls. Three stations or transmitters are necessary to determinate the mobile station (MS) position. For each station a special code is attributed. In this paper, two approaches are evaluated in terms of localisation errors. The first one is based on the code division multiple access technique CDMA using Gold code. The second one is based on the new waveforms called the Modified Gegenbauer Functions. These functions allow specific waveforms for each base station with a good orthogonal propriety. In order to evaluate the performance of these systems the localisation errors are calculated for two channel models: the AWGN and the IEEE 802.15 4a using the Time Difference of Arrived TDOA technique. The simulations results show that our positioning system based on MGF gives a better performance than the DS-CDMA positioning system.**

***Keywords*—Ultra Wide Band UWB; Time Difference of arrival TDOA; Modified Gegenbauer Functions; IEEE 802.15 4a channel;**

I. INTRODUCTION

UWB technology is essentially the transmission and reception of ultra short electromagnetic energy pulses. Short pulses mean wide bandwidths, often greatly exceeding 25% of the nominal center frequency [1]. The UWB pulses are characterized by very low power transmission (< 10 microwatts) and wide bandwidths (>1 Gigahertz).

The UWB technology was initially developed for high data rate communication applications. However, this technology allows high accuracy positioning in the challenging multipath and looses due to the environments typically found inside buildings [2]. This technique can be used in masked environments, for example in tunnels, buildings, airports…etc. Associated to other positioning techniques like GPS or GNSS, UWB can provide a continuous localization from outdoor to indoor position and vice-versa. The ranging accuracy expected from UWB systems is better than 30cm in severe multipath environments. In this study, localisation system for the indoor application based on the Ultra Wide Band technique is simulated in two channel cases: the Additive White Gaussian Noise (AWGN) and the IEEE 802.15 4a channel [3]. Two multiple access techniques are compared: DS-CDMA and a new technique based on Modified Gegebauer Functions (MGF). So, in order to evaluate the performance of these systems, the localisation errors are calculated for different SNR values.

II. THE PROPOSED SYSTEM

A. The UWB waveforms

Several waveforms can be used to generate the UWB signal, such as Gaussian pulses, monocycle pulses or news waveforms based on orthogonal polynomials [4], such as Hermite or Gegenbauer functions [5]. The choice of the appropriate waveform depends on the application considered. In fact, each waveform gives a specific cross-correlation function and the obtained peaks and the position of peaks must be easily detectable in order to have a good precision. Some studies compared these waveforms in terms of BER, the peak of correlation [5].

In this paper, two waveforms are used. The Gaussian waveforms associated to DS-CDMA technique in order to differentiate between the transmitter signals. The second one is based on the orthogonal waveforms, especially the Modified Gegenbauer waveforms.

The Gaussian pulse [6], Fig.1, has a waveform described by the Gaussian distribution. In the time domain, the expression of the Gaussian pulse waveform is given by (1):

$$g(t) = A\exp[-(t/\sigma)^2] \quad (1)$$

Where A stands for the maximum amplitude and σ for the width of the Gaussian pulse.

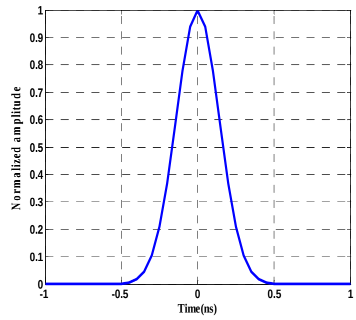

Figure 1. Time representation of Gaussian waveform

The orthogonal waveforms, using in this paper, are based on the Modified Gegenauber Functions. These functions allow us to modulate the data and, simultaneously, guarantee the multi-user system [6,7]. The MGF [5,3] $G_n(\beta, x)$ uses the weight function $W(x) = (1 - x^2)^{\beta - 1/2}$ where $\beta > -1/2$ is a shape parameter, n is the degree of the function and x is the variable. These functions are orthogonal on the interval $[-1,1]$ for $m \neq n$:

$$\int_{-1}^{1} w(x) G_n(\beta, x) G_m(\beta, x) dx = 0 \quad (2)$$

These functions can be defined by the recurrence relation.

Furthermore, they satisfy the differential equation.

$$G_n(\beta,x) = 2\frac{n+\beta-1}{n} x G_{n-1}(\beta,x) - \frac{n+2\beta-2}{n} G_{n-2}(\beta,x) \quad (3)$$

Their expressions for the first few orders are given by the following equation:

$$G_0(\beta,x) = (1-x^2)^{\beta-1/2}$$

$$G_1(\beta,x) = 2\beta x(1-x^2)^{\beta-1/2} \quad (4)$$

$$G_2(\beta,x) = \beta[-1+2(1+\beta)x^2](1-x^2)^{\beta-1/2}$$

$$G_3(\beta,x) = \beta(1+\beta)[-2x+(2+\beta)\frac{4x^3}{3}](1-x^2)^{\beta-1/2}$$

$$G_4(\beta,x) = \beta(1+\beta)\left[\frac{1}{2} - 2(2+\beta)x^2 + (2+\beta)(3+\beta)\frac{2x^4}{3}\right](1-x^2)^{\beta-1/2}$$

The waveforms of the MGF are given in Fig.2, for $n = 0$ to 4 and $\beta = 1$.These waveforms are normalized here so as to have an energy of unity.

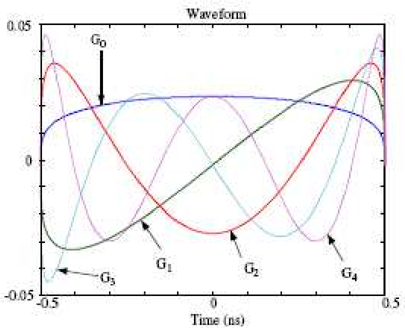

Figure 2. Time representation for modified Gegenbauer functions of orders n = 0 to 3.

B. *the localisation technique*

Various parameters of a radio signal can be used to perform radiolocation, such as [8, 10]:

- Signal Strength: Thus by exploiting the one-to one relationship between the signal strength and distance, an estimate of the distance is obtained. This technique is inoperable in a multipath environment.
- Angle Of Arrival (AOA): this technique is based on determining the direction of the arrival signal. A stationary device measures the angle of arrival of the signal sent by a mobile device. Location can be estimated through triangulation if at least two stationary devices perform measurement. Measuring angles requires a special antenna array.
- Time Of Arrival (TOA): In TOA positioning, a mobile device sends a signal to a stationary device, which sends it back to the mobile device. The mobile device measures the round-trip time (RTT) of the signal. This leads to a circle, whose radius corresponds to half of the RTT and centre is on the location of the stationary device. Location of the mobile device can be approximated to be at the intersection of at least three measured circles. This technique requires accurate clocks because a 1.0 s error in timing equals to a 300 m error in distance estimate. Thus, the accuracy is too low for TOA positioning.
- Time difference of arrival (TDOA): TDOA positioning is developed to eliminate the tight synchronization requirement of TOA. In fact TOA range measurements require synchronisation among the mobile station (MS) and the Base Station BS (transmitter). However, TDOA measurement can be obtained even in the absence of synchronisation between MS and BS, if there is synchronisation among the base stations. In this case, the difference between the arrival time of two signals travelling between the MS and BS is estimated. This locates the MS on a hyperbola with foci at the BS.

In this paper in order to lessen synchronisation effects, we use the TDOA technique.

Let (x, y) be the source location, receiver, and (Xi, Yi) be the known location of i^th Base Station (BS) or transmitter, where i =2, 3...M, M being the total number of BSs taking part in the position location process. Moreover, assume that BS#1 is the controlling BS. The range difference between source and the i^th BS is

$$R_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2} \quad (5)$$

Now, the range difference between base stations with respect to BS#1 is given by

$$R_{i,1} = c\, d_{i1} = R_i - R_1 \quad (6)$$

where c stands for the velocity of electromagnetic waves ($3.10^8 m/s$) and $d_{i,1}$ for the TDOA between i^Th BS and BS#1. In order to find the x and y values, Chan's method [9,10] is used, producing two TDOAs, for the three base stations. So, the solution for x and y in terms of R_1 is written as:

$$\begin{bmatrix} x \\ y \end{bmatrix} = -\begin{bmatrix} X_{2,1} & Y_{2,1} \\ X_{3,1} & Y_{3,1} \end{bmatrix}^{-1} * \left\{ \begin{bmatrix} R_{2,1} \\ R_{3,1} \end{bmatrix} R_1 + \frac{1}{2} \begin{bmatrix} R_{2,1}^2 - K_2 + K_1 \\ R_{3,1}^2 - K_3 + K_1 \end{bmatrix} \right\} \quad (7)$$

$$
\begin{aligned}
K_1 &= X_1^2 + Y_1^2, \\
K_2 &= X_2^2 + Y_2^2, \\
K_3 &= X_3^2 + Y_3^2.
\end{aligned}
$$

$$
\begin{aligned}
R_{2,1} &= c\,d_{2,1}, \\
R_{3,1} &= c\,d_{3,1}.
\end{aligned} \tag{8}
$$

On the right side of the above equation, all the quantities are known quantities, except R_1. Therefore, the solution of x and y will be in terms of R_1. When these values of x and y are substituted into the equation $R_{2,1} = x_2 + y_2$, a quadratic equation in terms of R_1 is produced. Once the roots for R_1 are known, values of x and y can be determined. It should be noted that only the positive R_1 root must be considered. One of the roots of the quadratic equation is, in fact, either negative or too large to be within the cell radius.

III. Simulations Results

Two systems are studied, DC-CDMA/UWB and MGF/UWB, and compared in terms of localisation errors. The first system is based on DS-CDMA technique. So, for each emitter (Base Station) a pseudo code is attributed. In this study, the gold code is chosen due to its good orthogonality propriety. The bloc diagram for each transmitter (BS) is described in Fig.3. The transmitter is composed of the coded and the modulated (antipodal modulation) operation using Gaussian waveforms. The receiver unit, Fig.4, consists of the demodulated and decoded function in order to retrieve the signal of each BS. Finally, the localisation technique based on Time Difference of Arrival is used to calculate the MS position. The second system is based on the Modified Gegenbauer Function MGF. In this case, we attributed one order for each BS. For example, order 1 (G1) is for SB1, order 2 (G2) for BS2 and order 3 (G3) for BS3. The receiver unit consists in demodulating and calculating the MS position using TDOA technique.

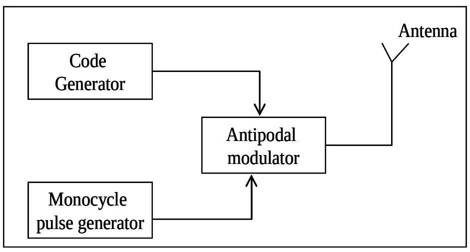

Figure 3. Bloc diagram of transmitter (or BS).

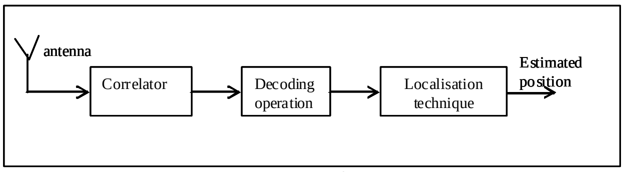

Figure 4. Bloc diagram of the receiver (MS)

In order to send information from one point to another, the transmitted signal must travel though the propagation area to reach the receiver (mobile station). In this paper, two channels are used: the AWGN channel with a uniform spectral power density and the IEEE 802.15.4a channel.

The IEEE 802.15.4a channels: The principal parameters included in this model are the presence of multi-path and losses of the signal in different environments. In our simulation, four types of IEEE 802.15.4a channels are used: CM1 (residential LOS Light Of Sight), CM2 (residential NLOS Non Light Of Sight) CM3 (office LOS), CM4 (Office NLOS).

In order to compare two systems DS-CDMA /UWB and the MGF/UWB, Fig.5, we calculate the localisation error for different SNR values and different waveforms numbers. In this case, the channel effect is a simple AWGN channel. We show that, when increasing the number of MGF, the localisation error decreases. For example, the localisation error is less then 1.5 cm for SNR>-10 dB when we attribute seven Gegenbauer pulses per base station.

For DS-CDMA solution, using code Gold length N=7chip, the localisation error is higher than 1.5 cm for SNR >-6 dB. We conclude that MGF gives a better performance than the DS-CDMA, even if we use one order for each transmitter system. These performances increase if we attribute more than one Modified Gegenbauer pulse per transmitter.

In the second step, Fig.6, we evaluate the proposed system performance (MGF-UWB, 8 MGF for each transmitter) in the case of IEEE 802.15.4a. We show that in the CM1 (residential LOS) case, the precision error is lower than 1.5cm. These performances decrease in the absence of line of sight. For SNR $\leq$ 0dB we have the same performances in three cases: CM1, CM2, CM3 except for CM4: NLOS and RMS delay spreads = 25 ns.

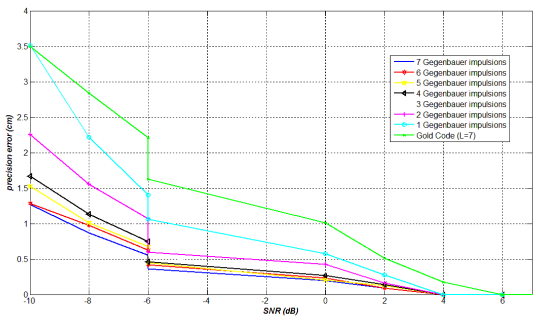

Figure 5. The localisation error for different SNR values.

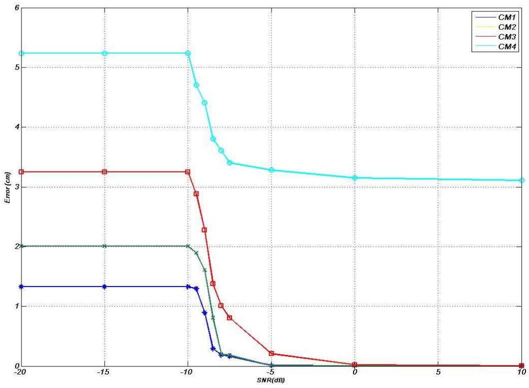

Figure 6. The localisation error for different SNR values in IEEE 802.15.4a channel case.

IV. Conclusion

In this paper, we study the indoor positioning system based on UWB technique. Two approaches are evaluated in terms of localisation errors. The first one is based on the code division multiple access technique DS-CDMA using Gold code. The second one is based on the new waveforms called the Modified Gegenbauer functions. In order to evaluate the performance of these systems the localisation errors are calculated for two channel models: AWGN and the IEEE 802.15 4a using the Time difference of arrived TDOA technique. The simulations results show that our positioning system based on MGF gives a better performance than the DS-CDMA positioning system.

Acknowledgment

We thank the International Campus on Safety and Intermodality in Transportation (CISIT) and the I-Trans competitiveness pole for their participation in supporting this work, as well as the National Agency for Research (ANR), which also supported this work through the PANsafer project.

References

[1] Di Benedetto, M.G. and Vojcic, B.R.: ”Ultra Wide Band (UWB) Wireless Communications: A Tutorial,” Journal of communication and Networks, Special Issue on Ultra-Wideband Communications, 2003, 5, 290-302.

[2] Young, D.P., Keller, C.M., Bliss, D.W. and Forsythe, K.W.: ”Ultra wideband (UWB) transmitter location using time difference of arrival (TDOA) techniques,” Thirty-Seventh Asilomar conference on Signals, Systems & Computers, Vol. 2 :pp. 12251229, Nov 2003.

[3] Available: http://ieee802.org/15/pub/TG4.html

[4] Abramovitz, M., and Stegun, I.A.,’Orthogonal polynomials’, in Handbook of mathematical functions with formulas, graphs and mathematical tables, ed. Dover, New York,1972.

[5] Elbahhar, F., Rivenq, A., and Rouvaen, J. M., ’Multi-user Ultra Wide Band communication system based on modified Gegenbauer and Hermite functions’, Wireless Personal Communications, **34**, 255–277, 2005.

[6] F. Elbahhar, A. Rivenq-Menha j, J.M. Rouvaen, M. Heddebaut and T. Boukour, Comparison between DS-CDMA and Modified Gegenbauer Functions for a multi-user communication Ultra Wide Band system, I.E.E. Proceedings Communications, 152, 1021–1028, 2005.

[7] F.Elbahhar ” Multi-user Ultra Wide Band communication system based on modified Gegenbauer and Hermite functions,” PhD. University of Valenciennes (France), 2003.

[8] Mok, E., Shea, G. and Yan, W.Y. ”Geolocation Positioning with Wireless Cellular Network in Hong Kong”, Hong Kong Institute of Surveyors Journal, Vol. 15, Issue 2, December 2004, pp.23-30.

[9] Chan Y.T.and Ho, K.C.A “simple and efficient estimator for hyperbolic location” IEEE transactions of signal processing, Vol.42, N° 8 Aug.1994.

[10] Laoufi, M. ”Localisation d’usagers de la route en dètresse par réseau de radiocommunications cellulaire d’appel d’urgence dédié”, Ph.D. thesis, 28/11/2003, University of Valenciennes, France