

**METHOD OF MULTIPLE ACCES COMMUNICATION IN A CENTRALIZED NETWORK
BASED ON AN ULTRA WIDEBAND IMPULSE PHYSICAL LAYER**

The invention relates notably to a method and system of
5 communication in a communications network supporting a physical layer of
ultra wideband impulse type, otherwise termed UWB (Ultra Wide Band) and
IR (Impulse Radio) respectively.

It applies, for example, in respect of communications in a network
of potentially mobile terminals, for which the users communicate either
10 towards a central point (base station B) commonly called "uplink" or
multipoint to point, shown diagrammatically in figure 1 or else simultaneously
pairwise (peer to peer links), represented in figure 2. In Figures 1 and 2, the
letter Ei represents a transmitter, the letter R a receiver and the letters Ui
various users, and the letter B the base station.

15 It applies, for example, in respect of an "ad hoc" network whose
local organization (in the form of a cluster or aggregate) allows the
designation of a node (master or coordinator) serving as synchronization
reference for the other nodes which are attached to it (figure 2) or to
networks benefiting from an infrastructure of base station type for cellular
20 networks (figure 1). It is assumed moreover that the type of receiver used at
each node is a linear receiver of "rake" type, described for example in
document [1].

It relates both to general-public applications and professional
applications. Professional applications involve, for example, applications of
25 networks of sensors or requiring temporary deployment in zones without
infrastructures for intervention teams of the public safety type (firemen,
doctors, special forces, maintenance teams in risk zones, etc.). General-
public applications involve, for example, applications of telephony or
multimedia information transmissions aimed at replacing cables with wireless
30 links.

A wideband or UWB-IR (ultra wide band Impulse Radio)
transmission uses the whole of the band of the channel, thereby requiring the

use of time division duplexing (TDD) to exchange data between two nodes. As a result, naturally, the access scheme used for this kind of transmission is time division multiple access (TDMA, AMRT in French).

Moreover, it is known that systems using TDMA are limited in capacity and the product of the number of users times the useful throughput per user is constant.

A way to increase the bandwidth of such a network is, for example, to combine a code division multiple access (CDMA) technique with TDMA which then allows several users to transmit during one and the same time horizon. CDMA in UWB-IR is made possible by the use of time-hopping codes (THC).

Like all code division multiple access CDMA systems, UWB-IR-THC (use of time-hopping codes) suffers from the phenomenon of interference caused by other users (MUI: Multi-User Interference).

In a general way, several schemes are potentially possible for reducing or canceling the phenomenon of multi-user interference or MUI. When restricting oneself to low-cost, low-consumption implementation solutions, one is then reduced to analog linear receivers of "rake" type where the decision is taken on a linear combination of delayed versions of the signal received. The only relevant parameter left in the design of the system for performance optimization is the datum of the time-hopping code. It is then possible to find a criterion which allows minimization of the output variance of the MUI at the output of the receiver and therefore enables the best performance to be ensured.

The transmission system's physical layer proposed according to the invention is, notably, based on the UWB-IR ultra wideband impulse technology.

The principle of UWB-IR is to transmit the information by means of very short impulses (of the order of a nanosecond) in baseband.

UWB-IR-THC transmission systems have essentially been described at the level of the physical layer, for example in document [1]. The idea of the THC is to transmit the impulses by spacing them out temporally in

a pseudo-random manner, each user having his own sequence. In principle this allows use of UWB in an asynchronous multi-user context. The use of this physical layer in practical systems is described for example in the two articles [2] and [3].

5 However, no prior art reference describes the way to achieve a multiple access system based on the use of time-hopping codes.

To the knowledge of the applicant, the only solutions proposed up till now for constructing the codes consist in applying the results of constructing codes dedicated to different transmission systems (essentially
10 dedicated to frequency hopping). An example is given in document [4]. These codes fall into the class of congruent codes, but do not comply with the criterion for minimizing the variance of the MUI considered here.

More recently, work published in [5] shows how to characterize the best codes (within the sense of the minimum variance of the MUI) for a UWB-
15 IR transmission using amplitude modulation (PAM: Pulse Amplitude Modulation).

The idea of the present invention relates notably to systems using position based modulation or PPM (standing for Pulse Position Modulation).

The invention relates to a method of multiple access communication
20 in a centralized network based on an ultra wideband impulse physical layer allowing multiple access based on time-hopping codes, each user being associated with a code, the transmission being performed in an asynchronous manner in a propagation medium with multiple paths, characterized in that a criterion is established so as to find the codes of the
25 Nu various users making it possible to minimize the variance of the multi-user interference J_n at the output of a linear receiver, the signal received $r(t)$ originating from a user being expressed in the form of a sum of the signal of interest $r_n(t)$ originating from user n and of a term corresponding to the multi-user interference, J_n where $r(t) = r_n(t) + J_n + n(t)$

30 with $r_n(t) = \sum_{k=1}^{N_p} A_n^k s_n(t - \tau_n^k)$ where A_n^k and τ_n^k are respectively the amplitude

and the delay of the k th path of the transmission channel between user n and the receiver,

and in that to determine the codes of the users use is made of the partial cyclic inter-correlations of the codes which satisfy the following criteria:

$$\begin{aligned} 5 \quad & \sum_{q=0}^{N_c N_f - 1} [C_{m,n}^{+2}(q) + C_{m,n}^{-2}(q)] = N_f^2, \\ & \sum_{q=0}^{N_c N_f - 1} C_{m,n}^{+}(q) C_{m,n}^{-}(q) = 0, \end{aligned}$$

for $m = 1, K, N_u$, $n = 1, K, N_u$ and $n \neq m$, where N_f is the number of frames, N_c is the number of chips, and N_u is the number of users transmitting to the central point or the number of point to point links simultaneously transmitting
10 in a point to point centralized network.

The communications between the users are, for example, point to point or multi-point to point communications.

The invention presents the advantages notably of obtaining time-hopping codes that guarantee high performance, notably in regard to service
15 quality, throughput, operating error probability or of increasing the number of simultaneous users.

Other characteristics and advantages of the invention will become more apparent on reading the description which follows given by way of wholly nonlimiting illustration accompanied by the figures which represent:

- 20 • Figure 1 a communication network comprising a central point,
- Figure 2 a communication network with point to point links, and
- Figure 3 the positioning of the impulses corresponding to a symbol in a frame.

25 **Description of the codes, optimization criterion.**

The PPM or pulse position modulated UWB-IR signal transmitted by user n may be written in a conventional manner:

$$s_n(t) = \sqrt{P_n T_f} \sum_k w(t - kT_f - \tilde{c}_n(k)T_c - \delta d_n(\lfloor k/N_f \rfloor) - \theta_n) \quad (1)$$

where $\{\tilde{c}_n(k), k = 0, \dots, N_f - 1\}$ is the time-hopping code of user n with values

in $[0, \dots, N_c - 1]$, $w(t)$ is the unit energy impulse, P_n is the mean transmission power, N_f is the number of frames per symbol, T_f is the width of the frame, T_c is the width of a code element better known by the term "chip", δ is the modulation index of the PPM, $d_n(k)$ is the series of symbols with values in $\{0, 1\}$, θ_n is a random variable equidistributed over $[0, N_f T_f[$ representing the asynchronism between the users, and $\lfloor x \rfloor$ denotes the integer part of x . The argument of the codes $\tilde{c}_n(k)$ in (1) has to be taken modulo N_f .

It is assumed that N_u users numbered from 1 to N_u transmit at the same time in a multipath propagation medium.

From the standpoint of a receiver (different from the N_u active transmitters), the expression for the signal received is then given by

$$r(t) = \sum_{n=1}^{N_u} r_n(t) + n(t) \quad (2)$$

where $n(t)$ is the noise at the receiver that is assumed to be white and Gaussian and $r_n(t)$ is the signal received originating from user n and the expression for which is:

$$r_n(t) = \sum_{k=1}^{N_p} A_n^k s_n(t - \tau_n^k) \quad (3)$$

where A_n^k and τ_n^k are respectively the amplitude and the delay of the k th path of the transmission channel between user n and the receiver.

A very general transmission channel model is assumed for which the amplitudes have zero mean (i.e. $E_A[A_n^k] = 0$) and are independent (i.e. $E_A[A_n^j A_n^k] = 0$ when $j \neq k$). It is assumed moreover that the various random parameters of the model are independent.

Let us assume now that one seeks to demodulate a particular user (user 1 will be chosen subsequently). The term of interest $r_1(t)$ is then identified in the signal received (2):

$$r(t) = r_1(t) + J_1 + n(t), \quad (4)$$

the term $J_1 = \sum_{n=2}^{N_u} r_n(t)$ then being identified as the multi-user interference.

The object of the invention consists notably in establishing a criterion which makes it possible to find the codes of the various users making it possible to minimize the variance of this interference so as to guarantee the best performance. It therefore involves calculating the variance of J_1 with respect to the random parameters of the model (amplitudes, delays, asynchronism), assuming the codes are deterministic.

In order to facilitate the calculation, (1) for example is represented in an equivalent form, which enables the contribution of the codes to be extracted from inside the argument of $w(t)$. The new representation may be written:

$$s_n(t) = \sqrt{P_n T_f} \sum_k \sum_{j=0}^{N_c N_f - 1} c_n(j) w(t - k N_f T_f - j T_c - \delta d_n(k) - \theta_n)$$

where $\{c_n(j), j = 0, \dots, N_c N_f - 1\}$ with values in $\{0, 1\}$ are the "developed" codes deduced from $\{\tilde{c}_n(j), j = 0, \dots, N_f - 1\}$, by the relation:

$$c_n(k) = \begin{cases} 1 & \text{if } k = \tilde{c}_n(j) + j N_c, 0 \leq j \leq N_f - 1, \\ 0 & \text{otherwise.} \end{cases}, k = 0, \dots, N_c N_f - 1.$$

Figure 3 illustrates the positioning of the impulses corresponding to a symbol in a frame. The time interval corresponding to a symbol is divided into N_f frames, each containing an impulse. The duration of a frame is divided into N_c "chips", the number of the "chip" in which the impulse is positioned being given by the value of the code $\tilde{c}(k)$. Figure 3 shows the position of the impulse corresponding to the symbol $d_n(2)$ and frame n°3 which is situated at "chip" n°2, corresponding to the code value $c_n(2 * N_c N_f + 3 * N_c + 2) = 1$.

The calculation of the variance of the multi-user interference is known to the person skilled in the art and will not be detailed. It follows for example the approach indicated in [5], namely, the successive calculation of the expectation according to the variables: amplitudes, symbols and

asynchronism.

The following result is obtained:

$$V_{\text{MUI}}^{\text{PPM}} = E_{A,d,\theta}[J_1^2] = \Psi_1 \cdot \sum_{n=2}^{N_u} P_n \cdot \phi_n \cdot [\kappa_{1,n} + \bar{\gamma} \cdot \xi_{1,n}] \quad (5)$$

where Ψ_1 is a constant dependent on the parameters of the propagation
 5 channel and the form of the impulse, ϕ_n is a constant dependent on the
 parameters of the channel and $\bar{\gamma}$ is a positive constant dependent on the
 impulse, with:

$$\kappa_{m,n} = \sum_{q=0}^{N_c N_f - 1} C_{m,n}^{+2}(q) + C_{m,n}^{-2}(q) \quad (6)$$

$$\xi_{m,n} = \sum_{q=0}^{N_c N_f - 1} C_{m,n}^{+}(q) C_{m,n}^{-}(q), \quad (7)$$

10 where $C_{m,n}^{+}(q)$ and $C_{m,n}^{-}(q)$ are the cyclic partial correlations between the
 developed codes of users m and n , defined by:

$$C_{m,n}^{-}(q) = \sum_{k=0}^{q-1} c_m(k) c_n(k-q), \quad (8)$$

$$C_{m,n}^{+}(q) = \sum_{k=q}^{N_c N_f - 1} c_m(k) c_n(k-q). \quad (9)$$

The partial correlations being positive or zero, the quantities $\kappa_{m,n}$
 15 and $\xi_{m,n}$ are also positive. Having regard to the positivity of the variables P_n ,
 ϕ_n and $\bar{\gamma}$, the minimization of (5) according to the codes amounts to
 minimizing each of the values of the set $\{\kappa_{1,n} + \bar{\gamma} \cdot \xi_{1,n}\}_{n=2}^{N_u}$. It can be proven
 that the minimum values of $\xi_{1,n}$ and $\kappa_{1,n}$ are respectively 0 and N_f^2 and that
 they can attain these minimum values simultaneously. In this case, the value
 20 $\kappa_{1,n} + \bar{\gamma} \cdot \xi_{1,n}$ has then been minimized independently of the value $\bar{\gamma}$.
 Consequently, the codes minimizing the variance of the multi-user
 interference (5), are those which satisfy:

$$\xi_{1,n} = 0 \quad \text{and} \quad \kappa_{1,n} = N_f^2, \quad n = 2, \dots, N_u \quad (10)$$

It is possible to characterize these codes in a simpler manner, through the

following lemma (not proven here):

$$\xi_{1,n} \text{ minimum } (\xi_{1,n} = 0) \text{ and } \kappa_{1,n} \text{ minimum } (\kappa_{1,n} = N_f^2) \Leftrightarrow \sum_{q=0}^{N_c N_f - 1} C_{1,n}^2(q) = N_f^2$$

where $C_{m,n}(q) = C_{m,n}^+(q) + C_{m,n}^-(q)$ is the cyclic intercorrelation between the developed code of user m and the code of user n . Thus a criterion equivalent to (10) for describing the set of codes which minimizes the variance of the multi-user interference is:

$$\sum_{q=0}^{N_c N_f - 1} C_{1,n}^2(q) = N_f^2 \quad n = 2, \dots, N_u. \quad (11)$$

It is possible also to establish a third equivalent characterization of the optimality of the codes:

$$\sum_{k=0}^{N_c N_f - 1} c_1(k) c_n(k - q) \leq 1, \quad q = 0, \dots, N_c N_f - 1, \quad n = 2, \dots, N_u \quad (12)$$

The criteria (10), (11) and (12) are equivalent and make it possible to verify whether a code is "optimal" in relation to user 1.

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CLAIMS

1 – A method of multiple access communication in a centralized network based on an ultra wideband impulse physical layer allowing multiple access
 5 based on time-hopping codes, each user being associated with a code, the transmission being performed in an asynchronous manner in a propagation medium with multiple paths, characterized in that a criterion is established so as to find the codes of the N_u various users making it possible to minimize the variance of the multi-user interference J_n at the output of a linear receiver,
 10 the signal received $r(t)$ originating from a user being expressed in the form of a sum of the signal of interest $r_n(t)$ originating from user n and of a term corresponding to the multi-user interference, J_n where

$$r(t) = r_n(t) + J_n + n(t)$$

with $r_n(t) = \sum_{k=1}^{N_p} A_n^k s_n(t - \tau_n^k)$ where A_n^k and τ_n^k are respectively the amplitude
 15 and the delay of the k th path of the transmission channel between user n and the receiver,

and in that to determine the codes of the users use is made of the partial cyclic inter-correlations of the codes which satisfy the following criteria:

$$\sum_{q=0}^{N_c N_f - 1} [C_{m,n}^{+2}(q) + C_{m,n}^{-2}(q)] = N_f^2 ,$$

$$20 \quad \sum_{q=0}^{N_c N_f - 1} C_{m,n}^{+}(q) C_{m,n}^{-}(q) = 0 ,$$

for $m = 1, \dots, N_u$, $n = 1, \dots, N_u$ and $n \neq m$, where N_f is the number of frames, N_c is the number of chips, and N_u is the number of users transmitting to the central point or the number of point to point links simultaneously transmitting in a point to point centralized network,
 25 where $C_{m,n}^{+}(q)$ and $C_{m,n}^{-}(q)$ are the cyclic partial correlations between the developed codes of users m and n , defined by:

$$C_{m,n}^{-}(q) = \sum_{k=0}^{q-1} c_m(k) c_n(k - q) , \text{ and}$$

$$C_{m,n}^+(q) = \sum_{k=q}^{N_c N_f - 1} c_m(k) c_n(k - q)$$

2 – The method as claimed in claim 1, characterized in that the communications between the users are point to point or multi-point to point communications.

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3 – The method as claimed in claim 1, characterized in that to determine the codes of the users use is made of the inter-correlations of the codes which satisfy the following criterion:

$$\sum_{q=0}^{N_c N_f - 1} C_{m,n}^2(q) = N_f^2,$$

10 for $m = 1, \dots, N_u$, $n = 1, \dots, N_u$ and $n \neq m$, where N_f is the number of frames, N_c is the number of chips, and N_u is the number of users transmitting to the central point (in multipoint to point, or uplink mode) or the number of point to point links simultaneously transmitting in a point to point centralized network.

15 4 – The method as claimed in claim 1, characterized in that to determine the codes of the users use is made of the inter-correlations of the codes satisfying the following criterion:

$$\sum_{k=0}^{N_c N_f - 1} c_m(k) c_n(k - q) \leq 1 \quad q = 0, \dots, N_c N_f - 1,$$

20 for $m = 1, \dots, N_u$, $n = 1, \dots, N_u$ and $n \neq m$, where N_f is the number of frames, N_c is the number of chips, and N_u is the number of users transmitting to the central point (in multipoint to point or uplink mode) or the number of point to point links simultaneously transmitting in a point to point centralized network.