A Suggestion of Multiple-Access Method for 4G-System

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Abstract - *Transmultiplexing as a method of multiple-access in 4G-system is suggested in this paper. Every existing linear method of multiple-access can be treated as a specific transmultiplexer. Moreover, transmultiplexing realizes the idea of intelligent network and reprogrammable electronic devices. The presented method uses perfect reversible integer-to-integer filter banks which have been attracting growing interest. Signals are then invertible in finite-precision arithmetics and map integers to integers. Due to this property, transmultiplexers of this type have important advantages: they can be applied for transmitting lossless compressed signals, minimal memory is needed and complexity of computations can be low.*

Keywords – *Transmultiplexing, 4G-system, multiple-access, spread spectrum, CDMA*

1. INTRODUCTION

The idea of 4G is to create a telecommunications system enabling a wide range of pieces of hardware to communicate with each other and to carry out a great deal of services in one network. There is a requirement to arrange not only phone-to-phone voice communication and data transfer between portable computer units or mobile phones. It has to be guaranteed that any future device will be able to connect to such systems as well. The 4G has to be not only hardware independent. The intention [1] is to create it as an extremely intelligent network. Therefore easily reprogrammable solutions are necessary to keep an opportunity for easy implementation of new services into existing networks without breaks and changes in equipment.

Dependence of users data and quality on one frequency subband was found as an arduous inconvenience. Interferences and noises occur on a narrow band, especially in radio communication. It implies a break of transmission for one or two users. It is much more convenient for telecommunications companies to spread these disturbances onto many users. In that way there will be no breaks and only a small loss of quality. Such idea, called typically spread spectrum, was implemented in FDM by frequency hopping and in CDMA. Obviously transmultiplexing enables it as well. According to mathematical models, transmultiplexers [2] are much more general systems. All linear methods of multiple-access are certain realizations of transmultiplexers with some banks of filters chosen in a specific way. This is not an easy task, although the necessary and sufficient conditions given in the *z*-domain are known [2]. The most popular multiple-access methods are presented in this paper as transmultiplexer realizations with proper integer-to-integer filter banks used. The new method of transmultiplexer filter design is presented.

2. TRANSMULTIPLEXING

Each transmultiplexer combines several signals into a single signal. Fig.1 shows the classic schematic diagram of the four-channel transmultiplexer. At the transmitter, the M input signals were upsampled, filtered and summed to obtain a composite signal. This composite signal can be transmitted over a single transmission channel. At the receiver end, the composite signal is relayed to four channels of the separation part, where the signal is filtered and downsampled to recover the original input signals. The system presented in Fig.1 consists of linear and time-invariant elements. This facilitates mathematical modelling of such systems.

The basic idea is the reversibility of all procedures of transmultiplexation in such a way that all output signals could be recovered as precisely as possible. For well-designed transmultiplexers, the output signal s_i^{out} approximates the input signal s_i^{in}, where i is the signal number, $i \in \{1, 2, \ldots, M\}$. A transmultiplexer achieves perfect reconstruction if s_i^{out} is only a delayed version of s_i^{in}, namely if there exists a positive integer τ such that

$$s_i^{\text{out}}(n) = s_i^{\text{in}}(n - \tau)\,. \qquad (1)$$

The dependence of output s_i^{out} from inputs s_k^{in}, where $i, k \in \{1, 2, \cdots, M\}$ is described [2] in the *z*-transform domain by equation

$$\bar{s}_i^{\text{out}}(z) = \frac{1}{M}\sum_{k=1}^{M}\bar{s}_k^{\text{in}}(z)\left[\sum_{m=0}^{M-1} H_k^c(w_M^m z^{1/M}) H_i^s(w_M^m z^{1/M})\right], \quad (2)$$

where $w_M = e^{-2\pi \cdot j/M}$ and $\bar{s}_i(z)$, $H^c(z)$, $H^s(z)$ stand for the z-spectrum of signal $s_i(n)$, combining and separation transfer functions, respectively. It means that each output signal depends on all inputs signals. The key point is that the constituent signals should be recoverable from the combined signal. To fulfil the perfect reconstruction condition (1), we obtain a set of M^2 equations

$$\frac{1}{M}\sum_{m=0}^{M-1} H_k^c\left(w_M^m z^{1/M}\right) H_i^s\left(w_M^m z^{1/M}\right) = z^{-\tau}\delta_{k,i}, \quad (3)$$

where $\delta_{k,i}$ is a Kronecker function. In that way a necessary and sufficient conditions for a crosstalk-free transmultiplexer were obtained [2].

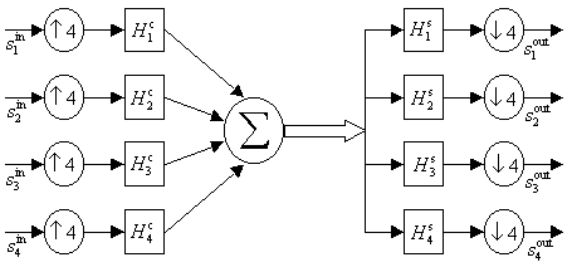

Fig. 1. A scheme of 4-channel transmultiplexer

Under assumption that all filters are FIR type of order I, conditions (3) are equivalent to

$$\sum_{l=\max\{0, Mn-I\}}^{\min\{Mn, I\}} h_k^c(Mn-l)\, h_i^s(l) = M\delta_{k,i}\delta_{n,\tau}, \quad (4)$$

where $h_i^s(l)$ means the $l \in \{0, \ldots, I\}$ coefficient of filter $H_i^s(z)$, $i \in \{1, 2, \ldots, M\}$. Similarly, $h_k^c(Mn-l)$ stands for the coefficients of the $H_k^c(z)$ filter. For each pair $i, k \in \{1, 2, \cdots, M\}$ of filter numbers, condition (4) gives $[2I/M]+1$ equations for $n = 0, 1, \ldots, [2I/M]$, where $[2I/M]$ means an integer part of $2I/M$. It results in the system of $M^2([2I/M]+1)$ equations. It is possible to find solution of system (4) only if transmultiplexer delay fulfils condition

$$\tau \in \left\{1, \ldots, 2\left[\frac{I-1}{M}\right] - 1\right\}$$

That means that delay must be at least equal to 1 and the maximal admissible delay is proportional to the order of filters and inversely proportional to the number of channels.

Now, let us consider the specific case when filters have low orders and a transmultiplexer system has a delay $\tau = 2$. Let the orders of all combining filters be equal to K and let K depend on the number of channels in the following way $K \le 2M - 1$. Let the order of all separation filters be $L \le 2M$ and, moreover, $h_i^s(0) = 0$ for all $1 \le i \le M$. For $p = 1$ and $p = 2$ let us introduce matrices

$$G_p^c = \begin{bmatrix} h_1^c(pM-1) & h_1^c(pM-2) & \cdots & h_1^c(pM-M) \\ h_2^c(pM-1) & h_2^c(pM-2) & \cdots & h_2^c(pM-M) \\ \cdots & \cdots & \cdots & \cdots \\ h_M^c(pM-1) & h_M^c(pM-2) & \cdots & h_M^c(pM-M) \end{bmatrix} \quad (5)$$

$$G_p^s = \begin{bmatrix} h_1^s(pM-M+1) & \cdots & h_M^s(pM-M+1) \\ h_1^s(pM-M+2) & \cdots & h_M^s(pM-M+2) \\ \cdots & \cdots & \cdots \\ h_1^s(pM) & \cdots & h_M^s(pM) \end{bmatrix} \quad (6)$$

which consist of combining and separation filter coefficients, respectively. All matrices

$$G_p^c, G_p^s \in \Re^{M \times M}$$

are square and their dimensions depend on number of channels. Under these assumptions, conditions (4) can be written in a simple form

$$\begin{cases} G_1^c G_1^s = 0 \\ G_2^c G_1^s + G_1^c G_2^s = ME \\ G_2^c G_2^s = 0 \end{cases}$$

where E is a unitary matrix. If we assume that matrix $G_1^c + G_2^c$ is nonsingular and

$$G_1^c(G_1^c + G_2^c)^{-1} G_2^c = 0, \quad G_2^c(G_1^c + G_2^c)^{-1} G_2^c = G_2^c$$

(G_2^c is singular!) then we obtain a simple method for separation filters designing

$$\begin{aligned} G_1^s &= M(G_1^c + G_2^c)^{-1} G_2^c (G_1^c + G_2^c)^{-1} \\ G_2^s &= M(G_1^c + G_2^c)^{-1} - G_1^s. \end{aligned} \quad (7)$$

It is possible to proceed in an opposite direction. We can assume the values of the coefficients of separation filters (i.e. matrices (6)) and compute the matrices (5) to obtain the coefficients of combining filters.

It is always possible to provide calculations using the rational numbers only. Sometimes integer values can be obtained. For this case it is convenient to use such filters that

$$\det\left(G_1^c + G_2^c\right) = 1.$$

3. MULTIPLE-ACCESS METHODS

It is possible to use a transmultiplexer as a multiple-access method and to model, for example, a spread spectrum CDMA presented in [3]. The examples of TDMA and CDMA, the major systems that combine the users' channels, realised as transmultiplexers with rational filter coefficients, are presented below.

3.1. Time Division Multiple-Access

TDMA is a basic method of multiple-access by allocating unique time slots to each user within a channel. The TDMA is an old solution, however, it is efficient in a range of environments. The system supports a variety of services (voice, data, fax, short message services, and broadcast messages). TDMA offers a flexible air interface, providing high performance with respect to capacity, coverage, and unlimited support of mobility and capability to handle different types of user needs.

The TDMA system can be very easily presented as transmultiplexer. In case of four users the following

$$h_1^{\mathrm{c}} = \begin{bmatrix}1\\0\\0\\0\end{bmatrix},\quad h_2^{\mathrm{c}} = \begin{bmatrix}0\\1\\0\\0\end{bmatrix},\quad h_3^{\mathrm{c}} = \begin{bmatrix}0\\0\\1\\0\end{bmatrix},\quad h_4^{\mathrm{c}} = \begin{bmatrix}0\\0\\0\\1\end{bmatrix}$$

values of combining FIR filters model TDMA. Simple computations give us the coefficients of separation filters

$$h_1^{\mathrm{s}} = \begin{bmatrix}0\\0\\0\\0\\1\end{bmatrix},\quad h_2^{\mathrm{s}} = \begin{bmatrix}0\\0\\0\\1\\0\end{bmatrix},\quad h_3^{\mathrm{s}} = \begin{bmatrix}0\\0\\1\\0\\0\end{bmatrix},\quad h_4^{\mathrm{s}} = \begin{bmatrix}0\\1\\0\\0\\0\end{bmatrix}.$$

3.2. Code Division Multiple-Access

The Code Division Multiple-Access (CDMA) system is probably the most commonly used spread spectrum system [4]. The spectrum of each user's signal is spread over the whole channel bandwidth. The narrowband data users signal is multiplied by a spreading signal - a very large bandwidth signal. All users in a CDMA system may transmit simultaneously by using the same carrier frequency. Different users' spreading signals are approximately orthogonal to each other. The receiver performs a correlation to detect data addressed to a given user, while signals from all the other users appear as noise. The receiver needs the spreading signal used in the transmitter for detection [5].

Our CDMA model uses filters which has coefficients orthogonal to each other. What is more, instead of typical upsampling, CDMA repeats M times each value of input signals, which is presented in Fig.2 by filters D which have coefficients

$$d = [1 \quad 1 \quad 1 \quad 1]^T.$$

In that example we consider filters

$$h_1^{\mathrm{c}} = \begin{bmatrix}1\\1\\1\\1\end{bmatrix},\quad h_2^{\mathrm{c}} = \begin{bmatrix}1\\1\\-1\\-1\end{bmatrix},\quad h_3^{\mathrm{c}} = \begin{bmatrix}1\\-1\\-1\\1\end{bmatrix},\quad h_4^{\mathrm{c}} = \begin{bmatrix}1\\-1\\1\\-1\end{bmatrix},$$

which represent the orthogonal Walsh functions.

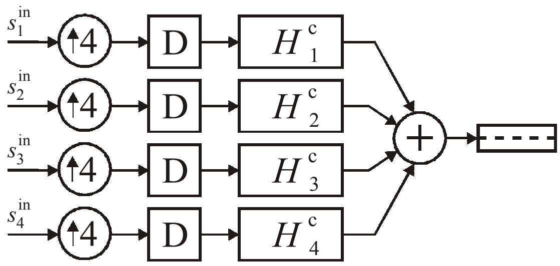

Fig.2. Combining part of transmultiplexer for CDMA modelling

3.3. Future solutions

Any existing or future solution of linear M multiple-access system is possible to be presented as certain realization of transmultiplexer system. Any linear multiple-access system can be written in the matrix form

$$s^{\mathrm{c}} = \sum_{i=1}^{M} A_i s_i,$$

where $A_i \in \Re^{nM \times n}$ are rectangular matrices whose dimensions depend on number n of input signal $s_i^{\mathrm{in}} \in \Re^n$ samples and $s^{\mathrm{c}} \in \Re^{nM}$ is a composed signal. Matrices A_i consist of coefficients h_i^{c}. The separation of signals can be written in the form

$$s_i^{\mathrm{out}} = B_i s^{\mathrm{c}}$$

where $B_i \in \Re^{n \times nM}$ are rectangular matrices which consist of coefficients of filters h_i^{s}. Sometimes it is difficult to design the required filters.

We adapt the transmultiplexer scheme (Fig. 1) for a given multiple-access system by choosing combining filter bank. The receiver side was always calculated on the basis of conditions, for example

(7), which enable us to compute the coefficients for separation filters.

3.4. An example of transmultiplexer

Let us assume composition filters

$$h_1^c = \begin{bmatrix} -1 \\ -1 \\ -1 \\ 1 \\ 0 \\ 0 \\ 1 \end{bmatrix}, \quad h_2^c = \begin{bmatrix} 1 \\ 1 \\ 1 \\ -1 \\ 0 \\ 1 \end{bmatrix}, \quad h_3^c = \begin{bmatrix} -1 \\ -1 \\ -1 \\ 1 \\ 1 \end{bmatrix}, \quad h_4^c = \begin{bmatrix} 1 \\ 1 \\ 1 \\ -1 \end{bmatrix}.$$

According to (5) we obtain

$$H_1^c = \begin{bmatrix} 1 & -1 & -1 & -1 \\ -1 & 1 & 1 & 1 \\ 1 & -1 & -1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix} \quad H_2^c = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix}.$$

All necessary assumptions are fulfilled and (7) gives

$$H_1^s = \begin{bmatrix} 4 & 4 & 4 & 4 \\ 4 & 0 & 0 & 4 \\ 0 & 4 & 0 & -4 \\ 0 & 0 & 4 & 4 \end{bmatrix} \quad H_2^s = \begin{bmatrix} 0 & 0 & 0 & -4 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}.$$

From these matrices and (6) we obtain

$$h_1^s = \begin{bmatrix} 0 \\ 4 \\ 4 \end{bmatrix}, \quad h_2^s = \begin{bmatrix} 0 \\ 4 \\ 0 \\ 4 \end{bmatrix}^T, \quad h_2^s = \begin{bmatrix} 0 \\ 4 \\ 0 \\ 0 \\ 4 \end{bmatrix}^T, \quad h_2^s = \begin{bmatrix} 0 \\ 4 \\ 4 \\ -4 \\ 4 \\ -4 \end{bmatrix}$$

The integer values of composite filter coefficients were assumed and the integer values of separable filter coefficients were obtained. This is a simple example where integer-to-integer filter banks were obtained. The characteristics of these filters are presented in Fig.3.

4. CONCLUSION

Transmultiplexer is a multiple-access system which provides an easy adaptation and co-operation with existing telecommunications systems. Transmultiplexing corresponds with the idea of an intelligent network and reprogrammable electronic devices. Any further linear solutions are easy to introduce by the change of filter coefficients. Such method is hardware-free, which is an important clue of 4G-system idea. Transmultiplexing is a very universal and efficient method so it could be a proper compliance of 4G-system requirements in terms of multiple-access. Filtering, upsampling and downsampling can be implemented in any kind of digital equipment.

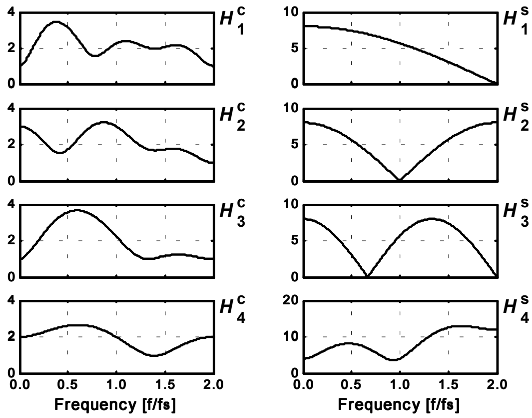

Fig.3. The amplitude filter characteristics: composition (on the left) and separation (on the right)

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