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# Simulation of Constant Modulus Algorithm Equalizer for Human Body Communication Channel

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## ABSTRACT

Human body can be used as a transmission medium for electrical signals which offers a novel data communication in biomedical monitoring systems. Human Body communication channel (on-body) may be proven as promising solution for Wireless Body Area networks (WBANs) in terms of simplicity, reliability, power-efficiency and security. In this paper, an algorithm is developed using MATLAB software for estimation and equalization of data travelled across human body transmission medium in the presence of EM noise. The human body is characterized based on ETRI's measurements as transmission channel (FIR Filter). An electric current is transmitted using signal electrode placed on body, within a specified frequency range of several MHz and received by signal electrode placed at other location(on body). The received noisy channel output data processing is done using constant modulus algorithm for batch equalization. The transmitted bits are extracted from received noisy data with no error bits i. e. a signal to error ratio (SER) near to zero is achieved. Results indicate that noise is effectively suppressed and error is converged over the HBC channel using adaptive CMA equalization.

## Keywords

Human Body Communication, Body Area Network, Signal electrode, CMA Equalization.

## 1. INTRODUCTION

Human body communication also referred as Body-coupled communication or Intra body communication in literature is a promising solution for Wireless Body Area Networks (WBANs). In this form of communication the human body acts as a transmission medium for electrical signals over a frequency range of 1MHz-100MHz.

For the frequencies more than 100MHz human body act like antenna and the communication is no longer limited to human body. Advantage of using human body as transmission media is, the full coverage is provided, while at the same time the communication range is limited to the close proximity of the human body. It largely prevents interference between HBC based WBANs and results in frequency reuse factor of close to unity i.e. every WBAN can use the same frequency band [5].

Conventional RF and UWB frequencies requires complex RF circuitry at higher powers of the order of mW. Whereas, direct transmission of signals through human body requires less power due to absence of high frequency front-ends [5].

Topology of WBAN constitutes two types of nodes, a Central Processing node(CPN) and many sensor nodes to monitor vital signals or signals of interest over the body. The traffic within WBAN is most of the time transmit only from sensor node to CPN node whereas CPN nodes communicates in transmit as well as in receiving mode. CPN sends wake-up signals and signals of critical conditions to the sensor nodes that require low data rates, at the same time must be highly prioritize, secure and consume minimum of the power. This type of communication can suitably be achieved using HBC [1]. Only one node of WBAN i.e. Central Processing Node (CPN) needs to be communicate wirelessly with other devices like, computer, Bluetooth, LAN or internet. This configuration improves batterylife upto 100% for sensor nodes and thus adds to the key issue of low power consumption in WBANs. Specifically ECG, Pulse oximetry or body temperature surveillance are key application areas [6].

As reported in many papers, HBC can be achieved via three mechanisms: simple circuit type, capacitive coupling type, and galvanic coupling type [8].

In this paper a simple arrangement of on-body (non-invasive) signal electrodes are used for transmitting and receiving the data signal, through the human body. Human body is considered as lossy dielectric medium having capacitive component. The frequency response is obtained that constitutes change of amplitude due to loss component of body and change in phase due to capacitive component of body. Using FDTD simulations and taking ifft of obtained frequency response, the time response of Channel transfer function is obtained. The resultant channel matrix is used to evaluate noisy channel output. The received noisy output from HBC channel at receiving electrode is estimated and equalized using Constant Modulus Algorithm (Batch type) to get actually transmitted bits with almost zero SER.

The outline of this paper is as follows: a description of measurement set-up is given in section II, an intrinsic channel model (on body) is presented in section III, signal and system model for estimation is discussed in section IV, section V constitutes simulation results and in section VI the conclusion is drawn.

## 2. MEASUREMENT SET-UP

In the HBC, a data signal is transmitted through the body of user, so a data communication can be accomplished without wire and wireless. To transfer a signal between transmitter and body or receiver and body, the transmitter and the receiver for the HBC have a metal plate signal electrode attached to the body. The signal electrode transfers a signal from the transmitter to the body while transmitting signal, or from the body to the receiver while receiving signal. The data is based on ETRI's measurement campaign for IEEE P802.15 Working group for Wireless Personal Area Networks (WPANs) [2].

The channel model for HBC is composed of the frequency response and the noise characteristics as shown in Fig.1.

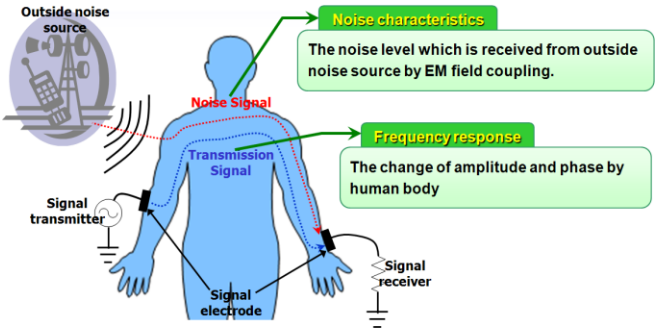

**Fig.1 Channel model for HBC**

Individual users of HBC have a different frequency response. The limbs of each user have a different physical length, so each user has a different transmission distance. Also, each user has a different composition of tissues. For example, the more weight the user has, the more composition ratio of muscle and fat tissues the user has. Hence, the frequency response has a uniform deviation range.

An EM (Electro-Magnetic) wave is radiated from a lot of electronic devices and the users of HBC are exposed to this EM wave during the data communication. Hence, the EM wave causes a noise signal inside body, so this noise signal as well as the data signal is received at the receiver electrode. The noise has different characteristics according to site and time, so its characteristic has to be defined statistically for exact modelling. The noise voltage is measured with multiple locations for a long time, so the site where the largest noise voltage is measured for the longest time is selected and its statistical parameters are defined as the noise characteristics.

The frequency response had been taken in the frequency range of 0 – 55MHz with measurements taken in steps of 5MHz. The values at 0 and 55 MHz are interpolated The response as shown in Fig.2 is obtained by locating the transmitter and receiver electrode on the fingertips of thumb of each hand (at transmission distance of 150cm), the size of metallic signal electrode is $2x2cm^2$ and the load impedance of receiver electrode is 10Mohm. The measured noise has a Gaussian distribution as shown in Fig.3. The mean and variance values are zero and $2.55\times10^{-5}$ respectively.

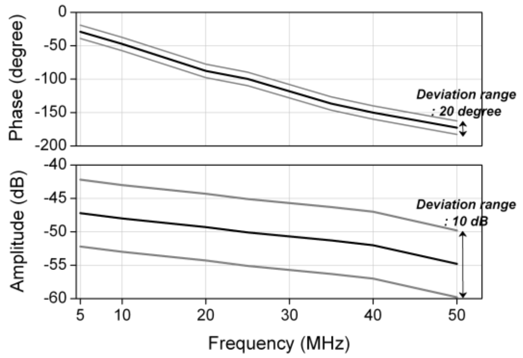

**Fig. 2 Frequency response**

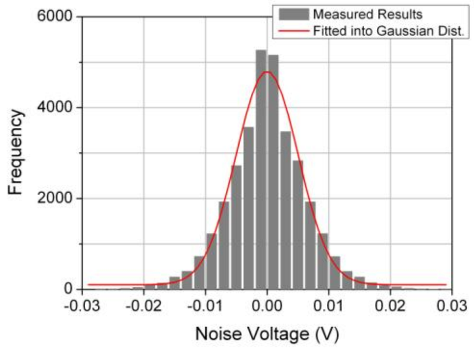

**Fig. 3 Noise characteristics**

## 3. HUMAN BODY COMMUNICATION MODEL

Intrinsically the human body in considered to be a FIR filter and its channel matrix is calculated by evaluating the time response from the Inverse Fast Fourier transform of the available frequency response. The frequency response constitutes channel attenuation in dBs and phase change in degrees over the frequency range 0-55 MHz. FIR filter is designed via frequency sampling technique. This technique is used to design non prototype filters having desired frequency response of any irregular shape with filter's transition bandwidth equal to the transition bandwidth chosen.

Interpolated frequency response is same as desired frequency response only at sampled frequencies and there will be finite error present at all other frequencies.

## 4. SIGNAL AND SYSTEM MODEL FOR EQUALIZATION

The transmitted bits in the form of ±1 are convolved with obtained channel matrix and EM noise is added for obtaining the noisy channel output data. The noisy data is equalized via a (stochastic) gradient descent algorithm such as the constant modulus algorithm (CMA). This algorithm uses the matrix based signal and system model as given by:

i.e. $\underline{X}(n) = H.\underline{S}(n) + \underline{V}(n)$..................(1)

$$\begin{bmatrix} x_n \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ x_{n-N} \end{bmatrix} = \begin{bmatrix} h_0 & \cdot & \cdot & h_L & & & & \\ & \cdot & & & \cdot & & & \\ & & \cdot & & & \cdot & & \\ & & & \cdot & & & \cdot & \\ & & & & \cdot & & & \cdot \\ & & & & h_0 & \cdot & \cdot & h_L \end{bmatrix} \begin{bmatrix} s_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ s_{n-N-L} \end{bmatrix} + \begin{bmatrix} v_n \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ v_{n-N} \end{bmatrix}$$

Where,

$s_n$ is the symbol sequence which is uniformly distributed sequences of ±1.

$h_n$ is the FIR channel matrix, with length L and each row having non zero elements $h_0$ to $h_L$ whereas all other elements are zero.

$v_n$ is the AWGN noise with zero mean, i.i.d., and variance $J_v^2$.

$x_n$ are the received samples.

### A. *Blind Channel Equalization*

All physical channels (at high enough data rates) tend to exhibit ISI. Linear channel equalization, an approach commonly used to counter the effects of linear channel distortion, can be viewed as the application of a linear filter (i.e., the equalizer) to the received signal. The equalizer attempts to extract the transmitted symbol sequence by counteracting the effects of ISI, thereby improving the probability of correct symbol detection.

Since it is common for the channel characteristics to be unknown (e.g., at startup) or to change over time, the preferred embodiment of the equalizer is a structure adaptive in nature. Classical equalization techniques employ a time-slot

(recurring periodically for time-varying situations) during which a training signal, known in advance by the receiver, is transmitted. The receiver adapts the equalizer e.g., via LMS algorithm so that its output closely matches the known reference training signal. Since the inclusion of such signals sacrifices valuable channel capacity, adaptation without resort to training, i.e., blind adaptation, is preferred. The most studied and implemented blind adaptation algorithm is the constant modulus algorithm (CMA). CMA seeks to minimize a cost defined by the CM criterion. The CM criterion penalizes deviations in the modulus (i.e., magnitude) of the equalized signal away from a fixed value. In certain ideal conditions, minimizing the CM cost can be shown to result in perfect (zero-forcing) equalization of the received signal. Remarkably, the CM criterion can successfully equalize signals characterized by source alphabets not possessing a constant modulus [e.g., 16-quadrature amplitude modulation (QAM)], as well as those possessing a constant modulus (e.g., 8-PSK).

The CM cost function can be motivated using the temporary assumption that the source is binary valued i.e. $s_n = \pm 1$ . In this case, $s_n$ has a constant squared-modulus of one ( $|s_n|^2 = 1$ ). Under perfect symbol recovery we know that the output $y_n$ has the same CM property and can thus imagine a cost that penalizes deviations from this output condition. This, in fact, defines the CM cost function for a BPSK source

$$J_{CM/BPSK} = E\left\{\left(1 - |y_n|^2\right)^2\right\} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

### B. *Constant Modulus based adaptive equalization algorithm*

In most communication systems that employ equalizers, the channel characteristics are known a priori and, the symbol sequence have constant modulus, i.e., higher order statistics, e.g.

$$R_2 = \frac{E\left\{|s_n|^4\right\}}{E\left\{|s_n|^2\right\}} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This algorithm(CMA), basically forces equalizer output to have the same modulus by minimizing the cost function $J$ .

Where,

$$J = E\left\{\left[\left|f^H \underline{X}(n)\right|^2 - R_2\right]^2\right\} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Algorithm:

Initialization $\underline{f}_0$

For n=1,2,……

$$\underline{f}_{n+1} = \underline{f}_n - \mu * 2\left[f^H \underline{X}(n) - R_2\right] * \underline{X}(n) * X^H(n)\underline{f}(n)$$

Error function is

$$e_n = \left|\underline{f}^H \underline{X}(n)\right|^2 - R_2$$

Check SER

A significant feature of the Constant Modulus Algorithm is its simplicity. Moreover, it does not require training sequence hence bandwidth efficiency is improved. Indeed, it is the simplicity of the CMA algorithm that has made it the standard against which the other linear adaptive equalization algorithms are benchmarked.

## 5. SIMULATION RESULTS

Using MATLAB a code is developed for intrinsic channel as FIR filter. The resultant channel matrix is convolved with the input data and external EM noise is added to get the noisy channel output data. The noisy channel output data is equalized using non training based adaptive CMA algorithm to extract the transmitted data symbols (±1). Total 1000 symbols are transmitted and smoothing length is 16(N+1=16). A Plot consists of four subplots of transmitted, received equalized symbols and error convergence for adaptive CMA equalizer is as shown in Fig. 4. This receiver results in SER=0 i. e. an exact equalization is achieved with no error. Also the plot of convergence for μ=0.001 is obtained for CMA adaptive equalizer which indicates that error has a reducing trend, as shown in fourth subplot of Fig. 4.

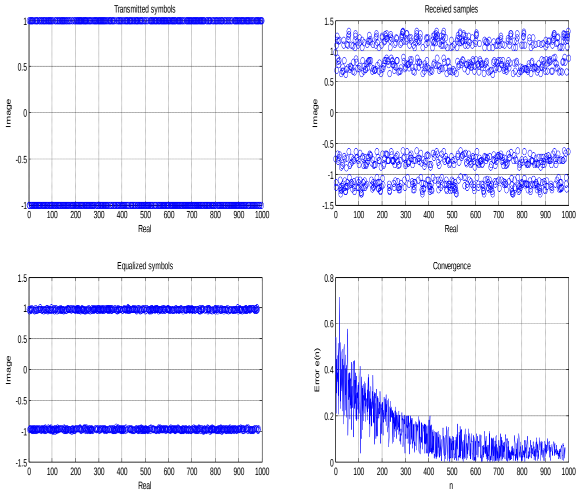

**Fig. 4 Transmitted, Received, Equalized symbols and error convergence for Adaptive CMA equalizer (μ=.001)**

## 6. CONCLUSION

Human Body Communication appears to be a better solution for WBAN's in terms of reliability, security and power efficiency. HBC channel has signal attenuation of upto 57.5dB for frequency range of 0-55MHz. HBC channel model is developed and data bits(±1) are transmitted through it, the received noisy data is estimated and equalized successfully using Constant Modulus based batch algorithm. The developed equalizer is superior than conventional MMSE based equalizers as no training is required for estimation and detection [9]. Hence bandwidth efficiency is improved. It also has track time variation and reduced computational complexity. In future the effect of chosen frequency range on the human body needs to be analyzed. The influence of body movement over the channel model may also be considered.

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