行政院國家科學委員會專題研究計畫成果報告

短距離 Gbits/sec 無線通訊之研究

Investigation of short-distance Gbits/sec communications

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一、中文摘要

我們提出一個利用多路徑衰降以增進傳輸效能的短距離通訊系統. 在此系統中, 多路徑問題是在傳送端處理而非接收端. 我們設計一個通道處理器以量測通道特性, 並依此改變信號大小, 以使接收信號具有正確的極性及振福. 我們進行理論分析和電腦模擬並且討論相關的課題.

關鍵詞: 多路徑衰降、短距離通訊、通道.

Abstract

A transmission scheme utilizing multipath-induced inter-symbol interference (ISI) to assist high-speed short-range wireless communications is proposed. In such a system, the multipath problem is handled mostly at the transmitter. A multipath processor (MP) is developed to measure the multipath channel response coefficients and estimate the amount of ISI on the transmitted data, and then modify the signal amplitude accordingly. Thereafter, the received signal will have the desired magnitude and polarity via the assistance of multipath-induced ISI. We will provide system analyses as well as simulation results and discuss related issues.

I. Introduction

Since Federal Communications Commission (FCC) approved the deployment of UWB on an unlicensed basis [1], short-distance wide-bandwidth communication systems had drawn more and more attention. Such systems with large transmission bandwidth will result in impulsive nature and be prevented from overlapping significantly in multipath-dominated environment because of the ability of fine resolution of multipath arrivals [2]. However, while the data transmission rate is up to the Gbps level, which resulting in subnano-second repetition interval, the multipath-induced ISI will become a critical problem [3].

Traditionally, the simplified optimum receiver structure, a RAKE front end followed by an MMSE equalizer, would be applied to solve ISI problems [3]. However, the large number of resolvable paths makes RAKE receiver structure hard to obtain essential pieces of the energy in the received multipath components. Therefore, several sub-optimum receiver structure for energy capture were proposed instead, such as the partial RAKE structure, transmit reference scheme with an autocorrelation receiver [4][5], the differential scheme with energy detector [2][6], as well as the decision feedback autocorrelation receiver [7]. Also, a distinctive sub-optimum structure called the time reversal scheme was mentioned [8]. In the time reversal system, the transmitter can acquire the channel impulse response and employ it to build a pre-filter to compensate the multipath channel.

In the high-speed short-distance systems, short-distance enables the high signal-to- noise ratio (SNR) transmission whereas high-speed may lead to serious multipath-induced ISI [3]. Hence, the ISI effect is crucial to the performance in such a transmission environment. In this paper, we attempt to deal with the ISI problem directly at the transmitter rather than at the receiving end. The advantages of managing ISI problem at the transmitting end are the availability of previous and upcoming data information and little noise is included in signal processing. Specifically, the multipath coefficients can easily be measured at the transmitter in short-distance communications. Moreover, since most system complexity will be located at the transmitter, the receiver structure can be much simplified, being suitable for 1-to-N systems. In the proposed system, a multipath processor (MP) similar to the infinite impulse response (IIR) filter structure is designed to measure the multipath coefficients first. After the measuring procedure, the MP estimates the effect of the multipath-induced ISI produced by the past data and then modifies the amplitude of the current data. While simple 1/-1 bipolar signaling is applied, the MP can accurately modify the transmitted signal amplitude so as to achieve nearly multipath-free transmission.

II. Channel Model and Measurement

1. Channel Model

Using discrete-time signal representation, the general channel impulse response shown in [6] will be modified as

$$h[n]=\sum_{l=0}^{N} a_l e^{j\theta_l}\delta[n-l] \qquad (1)$$

where a_l and θ_l represents the relative magnitude and phase of the l-th path, respectively.

To accomplish the multipath-assisted system, both forward and backward channel impulse responses as shown in Fig. 1 should be considered, in which $h_f[n]$ is the forward impulse response (FIR) and $h_b[n]$ is the backward impulse response (BIR). Since bipolar pulses are adopted in our system, θ_l in Eq.(1) can be simplified to 0 or π to represent signal polarity. Then the impulse responses are given respectively as

$$h_f[n]=\sum_{l=0}^{N}\alpha_l\delta[n-l] \qquad (2)$$

$$h_b[n]=\sum_{l=0}^{N}\beta_l\delta[n-l]. \qquad (3)$$

where α_l and β_l are real numbers, while N_f and N_b are the number of FIR and BIR components, respectively. For simplicity, we assume $N_f = N_b = N$ in the following analysis.

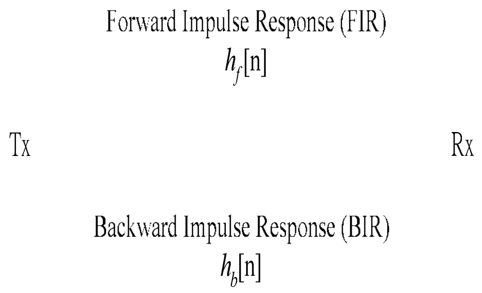

Fig. 1 Bi-directional channel model

We adopt the channel model described in [9] to specify the channel characteristics. Such an indoor UWB channel possesses two unique properties. One is the clustering property of the arrival paths, which results in unevenly distributed arrival times. The other is the rather small number of scatters within one resolvable path, usually no more than 2 or 3. Hence, two statistical models, the two-state Markov Model coupled with modified Poisson distribution and Gamma distribution, are employed to demonstrate the multipath arrival time and the power distribution, respectively.

In the arrival time model, g_i is the number of scatters in the *i*-th time bin. The state 1 means that no paths are present in the previous time bin, while the state 2 refers to the case that no paths are present in the previous time bin. The parameters are characterized as $\mu_1 = \int_{Tc}\lambda_1(t)dt$ and

$\mu_2 = \int_{Tc} \lambda_2(t)dt$ where $\lambda_1(t)$ and $\lambda_2(t)$ are the mean numbers of arrival within one time bin. In the power distribution model, the parameter $v_i = \varsigma_i^2$ is the power of the signal arriving in *i*-th time bin where ς_i represents the individual fading amplitude. The average power of fading amplitude is determined by an exponential decay from numerous measurement results which represents as $E[v_i] = e^{-\eta \cdot i}$ where η is the decay factor.

The forward and backward impulse responses for later simulation are based on the above channel model and the simulation will be mainly for light-of-sight (LOS) channel cases. Hence, the first multipath component will be multiplied by the LOS power-gain factor equal to 5dB relative to the second multipath component. Fig. 2 demonstrates the resultant responses with 225 multipath components and a time bin of 1ns. It is found that most of the significant multipath components are present within $t < 50ns$.

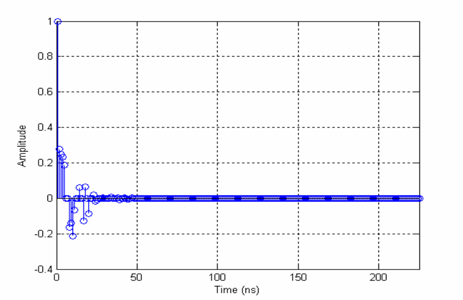

Fig. 2 Simulation result of the multipath channel.

III. System Description and Performance Analysis

1. System design concepts

While a series of data stream $D[n] = \sum_m d_m \delta[n-m]$, $d_m \in \{1,-1\}$, is sent from the TX to the RX via a noiseless channel, the received signal is obtained as

$$R[n] = D[n] \otimes h_f[n] = D[n] \otimes (\sum_{l=1}^{N} \alpha_l \delta[n-l]) \quad (4)$$

At some specific time instant, the received signal is formulated as

$$R[n]_{n=S} = r_S \cdot \delta[n-S] \quad (5)$$

and

$$r_S = \alpha_0 d_S + \sum_{l=1}^{N} \alpha_l d_{S-l} = \alpha_0 d_S + \Phi \quad (6)$$

where Φ is the amount of multipath-induced ISI resulted from the past data. Obviously, Φ is a random variable depending on the multipath coefficients and the polarity of past data. If the multipath coefficients are known at the transmitting end, we can pre-calculate Φ before d_S is sent. In fact, the affect of Φ on the received signal is twofold. When the polarity of Φ is same as that of d_S, Φ can be directly served as the received signal if its absolute magnitude is beyond some threshold. In this case, the TX is set to the idle state while the RX still can receive the signal with correct polarity. Therefore, we have the chance to save power via the assistance of multipath-induced ISI. On the other hand, when the polarity of Φ is opposite to that of d_S, we can modify d_S as

$$d_S' = \left\{ d_S - \sum_{l=1}^{N} \alpha_l \cdot d_{S-l}' \right\} \Big/ \alpha_0 \quad (7)$$

In this case, the received signal r_S is written as

$$r_S = \alpha_0 \cdot d_S' + \sum_{l=1}^{N} \alpha_l \cdot d_{S-l}' + \sum_{l=1}^{N} \alpha_l \cdot d_{S-l}' = d_S \quad (8)$$

Thus the desired data can be correctly obtained at the receiver.

Based on Eq.(8), we can completely eliminate multipath-induced ISI if the FIR coefficients are known exactly. From the results of previous section, we can obtain the FIR coefficients via the MP and reduce the variances of measured coefficients through the averaging processes. As it is easy to perform multiple measurements under short-range environment, the multipath coefficients could be accurately obtained. Meanwhile, since the cancellation of multipath-induced ISI is performed at the transmitting end, the affect of channel noises is absent.

2. Transmitted signal management

After explaining the design concept, we proceed to realize the multipath-assisted transmission. First, we have to develop a mechanism to estimate the amount of multipath-induced ISI and then modify the amplitude of transmitted data, if necessary. Fortunately, the MP can be directly converted to serve this purpose. After the FIR coefficients ($\alpha_l^{'}$) are measured, we can modify tap coefficients of the MP as

$$p_0 = 1/\alpha'_0 \ , \qquad (9)$$

$$p_l = -\alpha'_l \quad , \quad l = 1,2,...N \qquad (10)$$

Let the transmitted data $D[n] = \sum_m d_m \delta[n-m]$ be the input of MP and $\alpha'_0 = 1$ be set as the reference, we obtain the MP output as

$$D'[n] = \sum_m d_m^{'} \delta[n-m] \qquad (11)$$

and

$$d_m^{'} = d_m - \sum_{l=1}^{N} \alpha'_l \, d_{m-l}^{'} = d_m - \Psi \qquad (12)$$

where Ψ is the estimated multipath-induced ISI resulted from the past transmitted data.

When the modified data, $D'[n]$, is transmitted to the receiver via the multipath channel, the ISI effect is expect to lead the received signals to the desired polarity and magnitude. In order to verify our design, we assume the measured FIR coefficients be identical to the real ones and apply them to specify the tap coefficients of the MP. A total of 35 multipath components are considered. Then we perform computer simulation by sending data through the multipath channel with additive gaussian noise.

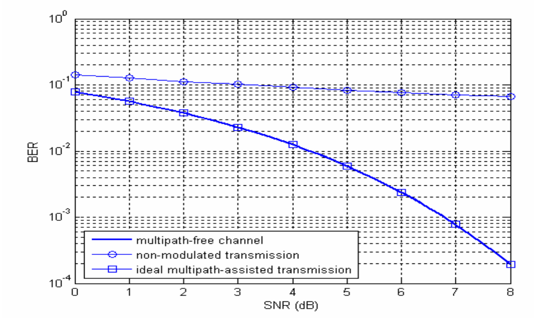

Fig. 3 Multipath-assisted transmission system verification and comparison

Fig. 3 is the bit error rate (BER) versus SNR for three different transmission systems. The thick solid line is the BER of the data passing through a multipath-free channel, being interfered only by the additive gaussian noise. It is treated as the reference for comparison. The performance of direct transmission without any ISI management is quite poor compared to the reference one, which implies that the ISI significantly degrades system performance. While the multipath-assisted transmission with the MP is employed, the simulated curve is rather close to the reference one, revealing that the proposed system can effectively eliminate the multipath-induced ISI.

In reality, there are two factors to preclude the MP system to achieve the multipath- free transmission. One is the consideration of system complexity that would limit the number of taps in the MP. The other is the unavoidable noise involved in the measurement procedure, making the measured multipath coefficients deviated from the real ones. Intuitively, we just have to obtain the essential and less noisy portion of the FIR coefficients instead of getting all of them. Moreover, the variance of $\alpha_l^{'}$ increases as l increases. Thus there may exist an optimum tap length of the MP, which would lead to a minimum BER. We perform computer simulation to find the optimum tap length. In the simulation, the FIR consists of 225 coefficients as shown in Fig. 2 and we perform 20 measurements to reduce the variance of the measured coefficients.

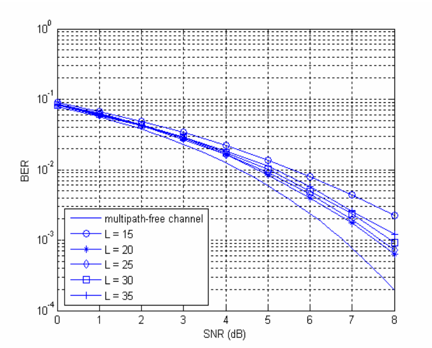

Fig. 4 BER vs. SNR for different MP tap lengths

Fig. 4 depicts the system BER for different MP tap lengths. For L=15, as the number of taps is insufficient, the performance obviously degrades with respect to the case of multipath-free transmission. For L=20, because sufficient number of taps are included, the performance is only about 1dB below the multipath-free case. But while *L* is getting larger, for example L=30, the BER is getting worse since some noisy multipath coefficients had been adopted. Thus the case of *L*=20 owns the minimum BER.

IV. Conclusion

In this paper, a concept applying bipolar signaling data in high-speed short-distance transmission with the assistance of multipath-induced ISI is proposed and the BER performance can approach that of the multipath-free condition. Although the real system considerations are simplified, the simulation results based on LOS channel environment demonstrate feasibility of the proposed system. The developed MP circuit at transmitter end provides the functionality of coefficients-measuring and ISI effect estimation. The measured channel response coefficients can be less deviated by applying many times measurements and average then. The ISI estimation mechanism can sufficiently release the ISI problem which the BER is about 1 dB less SNR than the miltipath-free case. Compare to the original MP, the refined version of MP with threshold mechanism can even conserves the transmission power and provides the rest time to the system. While the measured coefficients might make the MP output divergent, the dual-band MP is presented to release the divergence problem which extends the range of system usage. The on-off functionality is then appended on the dual-band MP to achieve the similar BER as the convergent coefficients case which is about 1 dB less SNR than the multipath-free case.

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