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An effect of phase noise for an indoor wireless system

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ABSTRACT

This paper gives an overview of 60 GHz indoor wireless channel characteristics and an effect on phase noise. The performance of OFDM system is severely degraded by the local oscillator phase noise, which causes both common phase error (CPE) and inter-carrier interference (ICI). In this paper, the phase noise suppression (PNS) algorithm in order to reduce the phase noise in OFDM-based 60 GHz WPANs is considered. The PNS algorithm is very simple and easily designed to realize system but it requires more effort to reduce the IC.

1. Introduction

Wireless personal area network (WPAN) technologies promise to link local device, within tens of meters, with high throughput wireless links. The 60 GHz band is of much interest since this is the band in which a massive amount of spectral space (5 GHz) has been allocated worldwide for dense wireless local communications. 60 GHz band for indoor broadband communication application has many attractive features such as wide bandwidth availability and strong attenuation by wall and oxygen in the air. Examples of applications include satellite cross link, collision avoidance system, and applications in military and commercial use. Commercial applications are short-range communication, wireless area network and wireless personal area network. In prospect, 60 GHz applications system will appear as a part of the next-generation wireless communications. BroadWay project is a representative research institute of IST in Europe. This project concept extends and complements existing 5 GHz broadband WLAN systems in the 60 GHz range for providing a new solution to very dense urban deployments and hot spot coverage. The trend has lately become a subject of special interest [1,2]. The newly formed IEEE 802.15.3c group is working on a 60 GHz WPAN standard [3].

Communication at 60 GHz is especially challenging. Using such high bandwidths and data rates requires substantial equalization of the received signal. To alleviate the burden in time-domain equalization, the most suitable technique for high-speed transmission at 60 GHz is OFDM. One of the most challenging problems in OFDM systems is phase noise produced by the local oscillators (LOs) in the transceivers. In practice, an LO signal generated by a voltage-controlled oscillator (VCO) operating at a relatively low frequency is multiplied to obtain a reference signal at a frequency near the carrier frequency. As a result, the phase noise produced by the original source is proportionally magnified. The phase noise encountered at 60 GHz, for instance, is about 22 dB higher than the phase noise at 5 GHz originating from the same source [1]. The influence of phase noise becomes the most critical when OFDM is combined with higher order modulation formats such as 16-QAM and 64-QAM [7,8]. In order to alleviate oscillator noise problems to a minimum, the OFDM sub-carrier

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spacing should be taken as high as possible (i.e., as high as delay spread allows) [8,9]. This approach also yields a number of side benefits; the required number of sub-carriers reduces for a given data rate target, and with that the processing complexity and interference problems due to nonlinear amplification. In order to alleviate oscillator noise problem to a minimum, a phase noise suppression algorithm is proposed [10]. This paper gives an overview of indoor wireless channel model and investigates an effect of phase noise on OFDM systems. In addition, consider performance analysis to minimize effect of phase noise on phase noise suppression algorithm. In Section 2, we discuss the channel model and property of 60 GHz band. In Section 2, we analyze the impact of phase noise on OFDM systems and investigate the phase noise suppression algorithm which is modified frequency domain one-tap equalizer. Simulation results and performance comparison are presented in Section 3. A conclusion is given in Section 4.

2. Phase noise analysis and phase noise suppression algorithm analysis of SINR

Indoor wireless channel model of Saleh–Valenzuela has to be characterized to help design a more reliable and efficient communication system. The model proposed by Saleh and Valenzuela is based on a clustering phenomenon observed in their experimental data [4–6]. In all of their observations, the arrivals came in one or two large groups within a 200 ns observation window. It was observed that the second clusters were attenuated in amplitude, and that rays, or arrivals within a single cluster, also decayed with time. Their model proposes that both of these decaying patterns are exponential with time, and are controlled by two time constants: Γ, the cluster arrival decay time constant, and γ, the ray arrival decay time constant. The cluster arrival times, i.e., the arrival times of the first rays of the clusters are modeled as a Poisson arrival process with fixed rate Λ. Within each, cluster, subsequent rays also arrive according to a Poisson process with another fixed rate λ. By definition, for the cluster, $T_0 = 0$, and for the first ray within the lth cluster, $\tau_{0l} = 0$. Thus, according to our model, T_l and τ_{kl} are described by the independent interarrival exponential probability density functions

$$p(T_l | T_{l-1}) = \Lambda \exp\left[-\Lambda(T_l - T_{l-1})\right], l > 0$$
$$p(\tau_{kl} | \tau_{(k-1)l}) = \lambda \exp\left[-\lambda(\tau_{kl} - \tau_{(k-1)l})\right], k > 0 \tag{1}$$

The amplitude of each arrival is given by β_{kl}, whose mean square value is described by the double-exponential decay. Mathematically it is given by

$$E[\beta_{kl}^2] \equiv E[\beta^2(T_l, \tau_{kl})] = E[\beta^2(0,0)] e^{-T_l/\Gamma} e^{-\tau_{kl}/\gamma} \tag{2}$$

where $E[\beta^2(0,0)]$ is the average power gain of the first ray of the first cluster.

Fig. 1 shows the conceptual interpretation for indoor wireless channels. Large exponential decaying pattern and small exponential decaying pattern are associated with arrival decay time constants Γ and γ, respectively.

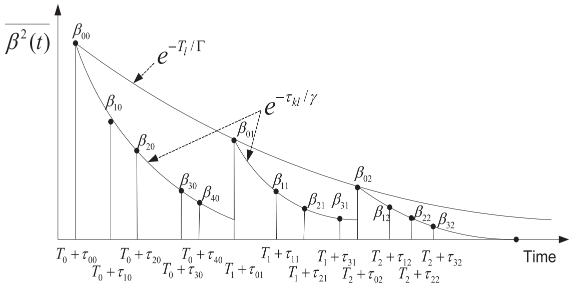

Fig. 1. Average power delay representation of indoor wireless channel.

Recall that $\{\theta_{kl}\}$ is a statistically independent uniform random variable over [0, 2π). Furthermore, the $\{\beta_{kl}\}$ is statistically independent positive Rayleigh distributed random variable. Mathematically, the impulse response of the multipath model is described as

$$h_i(t) = \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l}^i \delta(t - T_l^i - \tau_{k,l}^i) \tag{3}$$

where

- $\{\alpha_{k,l}^i\}$ is the multipath gain coefficients, i refers to the impulse response realization, l refers to the cluster, and k refers to the arrival within the cluster;
- $\{T_l^i\}$ is the delay of the lth cluster for the ith channel realization;
- $\{\tau_{k,l}^i\}$ is the delay of the kth multipath component relative to the lth cluster arrival time (T_l^i) (for the ith channel realization);
- Λ is thecluster arrival rate; and
- λ is the ray arrival rate, i.e., the arrival rate of a path within each cluster.

Frequency offset and phase noise effect on OFDM systems have been presented in many papers [7,8], and references therein. In this section, let us see the effect of the signal to interference plus noise ratio (SINR), caused by the presence of phase noise which is analytically evaluated. During a symbol period, transmitted OFDM signal can be expressed as the following:

$$x_m(t) = e^{j2\pi f_c t} \sum_{n=-N_g}^{N-1} x_m(n) g(t - nT/N) \tag{4}$$

where N_g, f_c, T, and $g(t)$ denote the length of CP, carrier frequency, symbol duration, and transmitted filter, respectively. Receiver filter and channel impulse response are denoted by $f(t)$ and $h(t)$, respectively. The received symbol can be expressed by

$$r_m(t) = e^{j2\pi f_c t} \sum_{n=-N_g}^{N-1} x_m(n) p(t - nT/N) + z_m(t) \tag{5}$$

$p(t)$ is expressed by $p(t) = g(t) \otimes h(t) \otimes f(t)$ where $\otimes$ denotes the circular convolution. $z_m(t)$ is an additive white Gaussian noise (AWGN) with zero-mean and variance σ_z^2. After frequency down-conversion, phase noise is produced by the local oscillators. It is assumed that frequency and timing synchronization are perfect, so we take phase noise into consideration. The received nth sample of the mth OFDM symbol can be expressed by

$$r_m(n) = x_m(n) \otimes h_m(n) \cdot \exp\left[j\phi_m(n)\right] + z_m(n) \tag{6}$$