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A realistic Wireless Channel Modeling in the Context of Highly Reliable Communications

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A realistic Wireless Channel Modeling in the Context of Highly Reliable Communications

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Abstract

The modeling of wireless channels has been ongoing for more than a century. The increasing utilization of wireless technology in a wide range of settings, along with the utilization of higher frequency bands, has necessitated the development of novel channel models, advanced modeling approaches, and enhanced modeling precision. it has become essential to estimate Channel State Information (CSI) in order to ensure dependable data transfer. As a consequence, this leads to precise receiver demodulation, accurate decoding, and equalization procedures. First part of This article provides basic concept of channels ,second part an overview of the fading phenomenon and a thorough examination of recent research conducted on the estimation of channel characteristics in wireless communication systems. This study examines recently developed channel estimation approaches, focusing on their different types and effectiveness. The text also discusses the comparison between them in terms of computing cost, simplicity, and appropriateness requirements. This study additionally presents a fundamental overview of the wireless channel model, as well as the SIMO and MIMO channels. third part of review, serves in Propagation and Wireless Channel Modeling, where we will examine these subjects. We provide an overview topics, including the current areas and methodologies used in active channel modeling. Additionally, we discuss how the emergence of new applications has led to more demanding criteria for precise channel modeling. In addition, we provide a concise explanation of the significance of precise channel modeling for emerging and prospective applications.

Keywords: propagation, measurements, wireless channel modeling

1.Introduction

The study and representation of wireless channels has a history spanning more than a century(Jordan, 1968) ,Over time, the modeling techniques have advanced from predicting the propagation of signals between dipole antennas over different types of terrain using narrowband, single-frequency signals below VHF, to using wideband, multi-antenna hybrid deterministic-stochastic spatio-temporal models for frequencies that reach the upper millimeter-wave and terahertz bands. Significant advancements have been made in channel modeling for optical communications. However, we will focus only on radio frequencies that are below the optical bands.

While satellite and aviation communications will continue to be crucial for long-range connections, commercial communication systems like cellular networks and WiFi have increasingly focused on short-range applications. These include vehicle-to-vehicle communication, indoor modeling, wireless links within computer chassis, and even on-chip wireless for integrated circuits.

The proliferation of wireless applications has led to a rise in the intricacy of channel models, which are used to depict the diverse range of surroundings. This includes the development of customized models tailored to specific sites, such as factories (Chizhik et al., 2020).As a result, computer-based modeling techniques such as ray-tracing (together with ray-launching) and more sophisticated mathematical models have been employed. Emerging applications, such as the fusion of communications and radar (Shi et al., 2021) and the integration of communications and sensing (Liu et al., 2022), necessitate the development of novel channel technologies.

Fading, commonly referred to as Rayleigh fading, occurs due to fluctuations in the phase and amplitude of broadcast signals caused by minimal space changes between a transmitter and receiver. A Rayleigh probability density function (pdf) is used to statistically describe the envelope of received signals in the presence of fading, where there is no line of sight and no dominant fading component. On the other hand, a Rician pdf can represent a narrow fading envelope when there is no dominant fading present(Sklar, 1997). Moreover, in extensive regions, the decrease in signal strength caused by movement or signal weakening correlates to macroscopic signal fluctuations. The Doppler shift is a feature of the wireless channel that occurs because the wireless communication channel changes over time or because there is movement between the transmitter and receiver(Sayeed and Aazhang, 1999) (Sayeed and Aazhang, 1999). The impact of multipath propagation is evident, as depicted in Figure 1, when the broadcast signal reaches the receiver as many signals due to reflections and scattering. The signals arrive at the receiving ends with different Doppler shifts, phase shifts, time delays, and amplitudes.

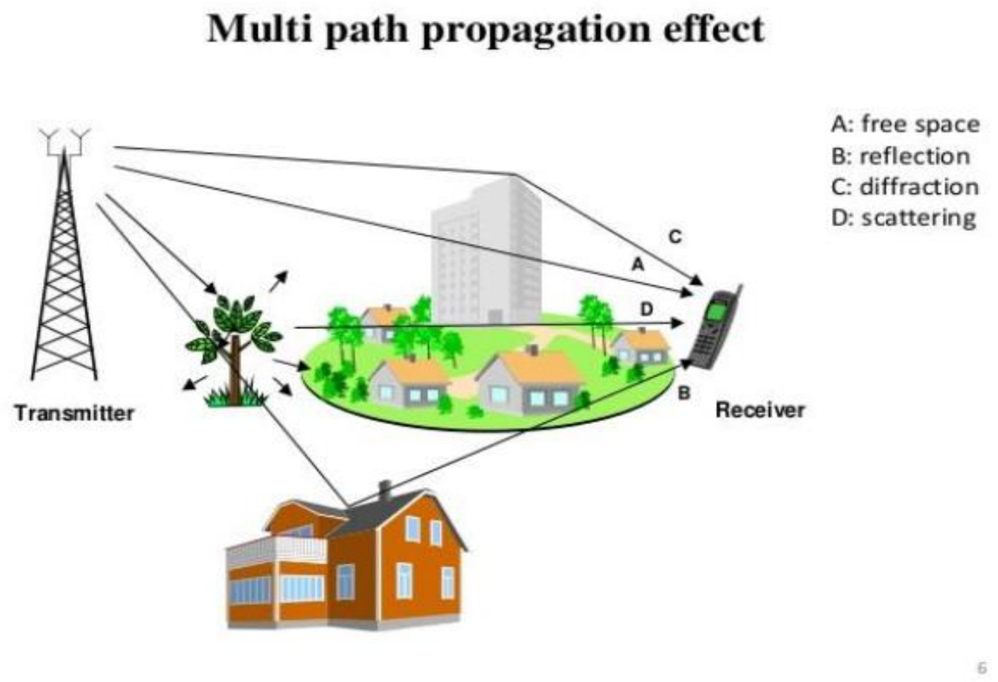

Figure 1: Multipath propagation in mobile communication system

Accurate provision of channel state information (CSI) is necessary at system receivers in order to achieve optimal performance for wireless communication systems. This allows transmitted signals to be detected in a coherent manner.

Alternatively, the only available approach to demodulate transmitted signals is a non-coherent method, such as the differential demodulation technique, which leads to a decrease in signal-to-noise ratio (SNR) of approximately 3-4 dB (Li et al., 1998) .Several studies have focused on the issue of channel estimation and have devised several approaches to obtain Channel State Information (CSI) at the receiver's end. The purpose of this is to minimize the impact of a decrease in Signal-to-Noise Ratio (SNR). This study focuses on discussing recent channel estimation strategies that have been investigated.

The organization of the paper is as follows:

First section :Basic concept of channel .Second and third section ,The wireless channel model is illustrated , provides an overview of existing research on channel estimate methods .fourth, fifth and sixth section, overview of the difficulties at hand and introduces the subjects that will be discussed at the special Propagation and Wireless Channel Modeling.", we provide a concise overview of various current areas of focus in channel modeling, following the introduction of the session contributions. explores contemporary modeling methodologies. senventh section: discussion and comparison .Eighth section: conclusion .ninths section References

1.Channel models basic concepts

1.1 Channel

The term "channel" denotes the medium that exists between the sending antenna and the receiving antenna, as depicted in Figure 2.

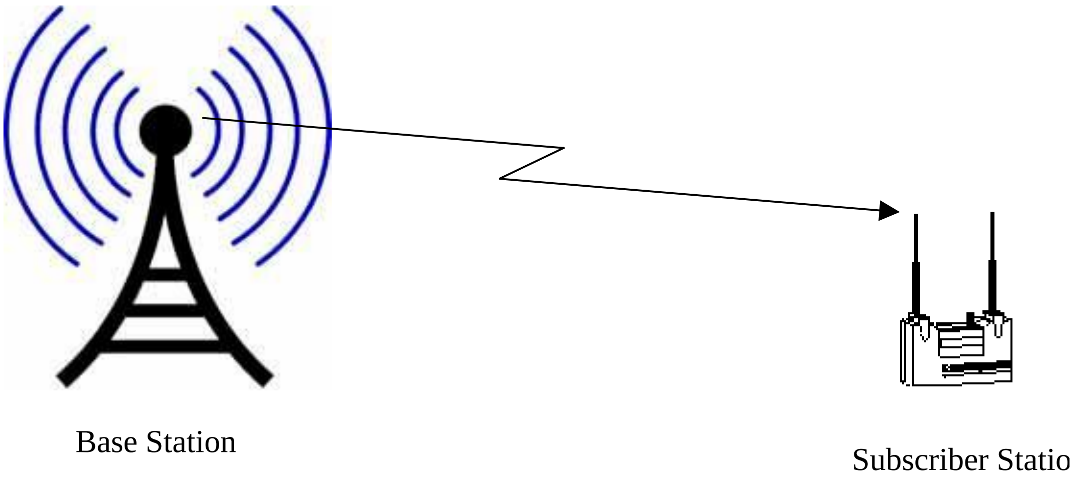

Figure 2: Channel

The properties of a wireless signal undergo modifications as it propagates from the transmitting antenna to the receiving antenna. The characteristics are contingent on the separation between the two antennas, the trajectory(s) of the signal, and the surrounding environment (including buildings and other objects) along the way. If we possess a model of the medium between the two, we can acquire the profile of the received signal by examining the profile of the broadcast signal. The term used to refer to this particular model of the media is "channel model".

Typically, the power characteristics of the received signal can be determined by combining the power characteristics of the sent signal with the impulse response of the channel by convolution. The process of convolution in the time domain is essentially the same as the process of multiplication in the frequency domain(Hari et al., 2000).

1.2 Path Loss

The most basic type of channel is the unobstructed line of sight channel, where there are no obstacles present between the transmitter and receiver, or along the path connecting them. In this straightforward scenario, the broadcast signal weakens due to the spherical dispersion of energy from the transmitting antenna. The received power for this line of sight (LOS) channel is determined by(Hari et al., 2000):

$$p_r = p_t \left[\frac{\sqrt{G_l}\lambda}{4\pi d}\right]^2 \qquad \text{- (1)}$$

Here, p_t denotes the transferred power, G_l is the product of the transmit and receive antenna field radiation patterns, λ represents the wavelength, and d signifies the distance. The power diminishes in direct proportion to the square of the distance, as per theoretical principles. Practically, the power diminishes at a faster rate, usually proportional to the cube or quartic power of the distance.

Ground presence induces wave reflection, allowing them to reach the transmitter. Occasionally, these waves that bounce back can experience a 180° change in phase, resulting in a decrease in the overall received power. The route loss can be approximated using a basic two-ray model:

$$p_r = p_t \frac{G_t G_r h_t^2 h_r^2}{d^4} \qquad \text{- (2)}$$

Here, $h_t$refers to the height of the transmitter antenna, while "h_r" refers to the height of the receiving antenna. It is important to observe that there exist three significant distinctions compared to the preceding formula. Initially, the heights of the antennas exert an influence.Furthermore, the wavelength is not present, and moreover, the exponent on the distance is 4.

1.3 Shadowing

If there are any obstacles (such as buildings or trees) in the course of the signal, a portion of the transmitted signal is attenuated due to absorption, reflection, scattering, and diffraction. The phenomenon is referred to as shadowing. According to Figure 3, if the base antenna acted as a light source, the intermediate building would create a shadow on the subscriber antenna. Therefore, the term shadowing is used.

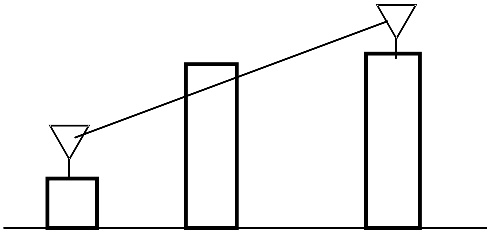

Figure 3: Shadowing

$$P_L(d)dB = \overline{P_L}(d_o) + 10log\left(\frac{d}{d_o}\right) + X \qquad - (3)$$

Let X be a random variable that follows a normal (Gaussian) distribution with a standard deviation of σ, measured in decibels (dB). X denotes the influence of shadowing. Shadowing can cause variations in the received power at positions equidistant from the transmitter, resulting in a lognormal distribution. The occurrence is known as lognormal shadowing **(Andrews et al., 2007)**.

1.4 Multipath

The wireless signal is reflected by objects positioned along its route. Additionally, certain of these waves that bounce back are also detected by the receiver. Due to the varying paths taken by each of these reflected signals, they exhibit distinct amplitudes and phases.

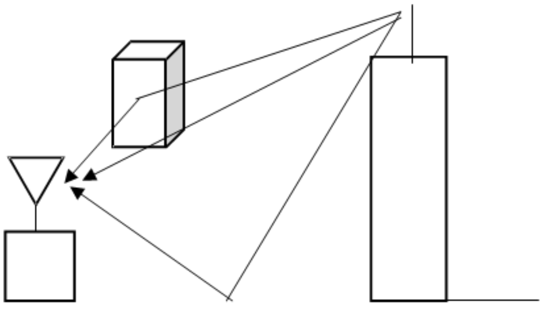

Figure 4: Multipath

The received strength at the receiver may be either raised or lowered depending on the phase of these numerous signals. Even a minor adjustment in position might lead to a substantial variation in signal phases and consequently affect the overall received power. Figure 5 clearly displays the three components of the channel response. The bold dotted line reflects the attenuation of signal strength. The lognormal shadowing alters the overall loss to match the value shown by the thin dashed line. The presence of multipath ultimately leads to fluctuations, as seen by the solid bold line. It is important to observe that fluctuations in signal strength caused by multipath interference occur throughout the distance range of the signal wavelength.

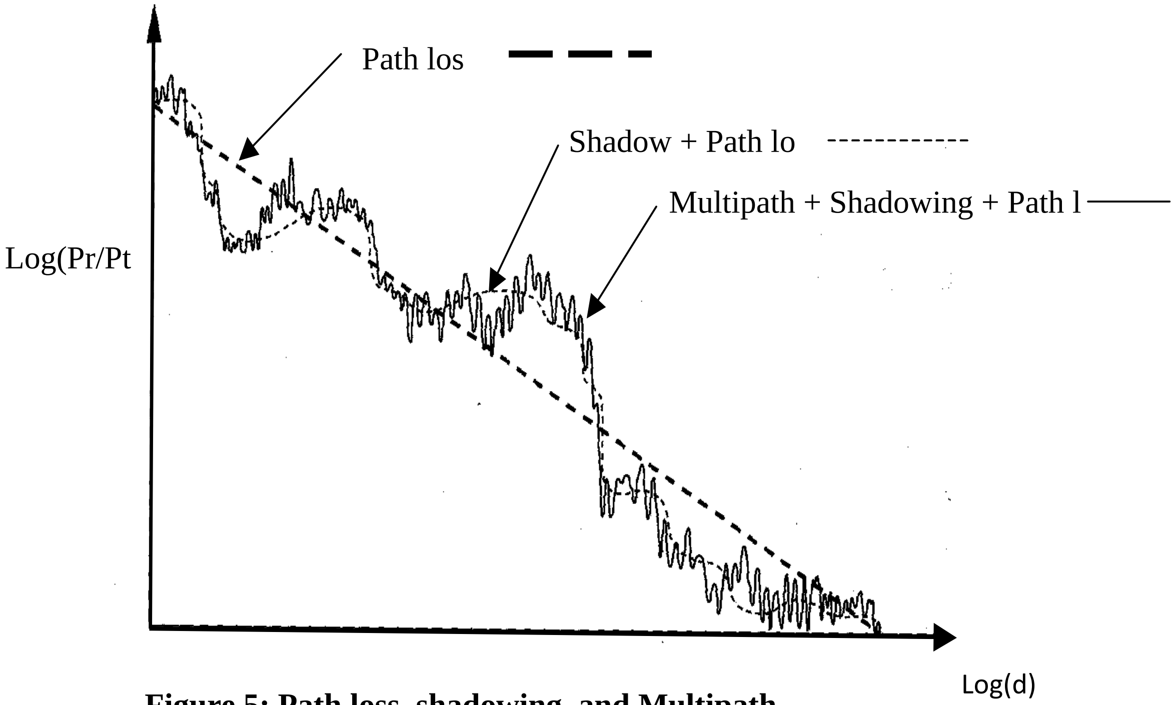

Figure 5: Path loss, shadowing, and Multipath

2-Wireless channel models

The wireless communication channel is often described by an impulse response vector, which contains the majority of the information needed to interpret signals conveyed across the channels. The channel impulse response (CIR) represents the immediate state of a dispersive channel caused by various multipath components. Vectors exhibit varying instantaneous amplitudes (Prasad, 2004).Let $s(t)$ represent the sent signal in a wireless communication, and $x(t)$ represent the equivalent complex baseband form of $s(t)$. $x(t)$ can be regarded as a multipath fading phenomenon.

$$s(t) = \mathrm{Re}\{x(t)e^{jw_c t}\} \qquad \text{- (4)}$$

The notation Re{·}(Prasad, 2004) represents the real portion, whereas ωc denotes the carrier frequency, which is equal to 2πfc. The current signal received is structured as:

$$\mathrm{r(t)} = \sum_{\mathrm{t=0}}^{\mathrm{L-1}} \mathrm{h_t(t)s(t - \tau_1(t))} \qquad \text{- (5)}$$

The variables L, $\tau l(t)$, and $hl(t)$ represent the number of pathways, the time-varying latency of each path, and the time-varying amplitude of each path, respectively.

3.Methods of Channel Estimation

Wireless communication signals commonly experience distortion, hence it is essential to convey information about any distortion through the channel estimation procedure. The performance accuracy of the wireless system is determined by the reliability of this procedure. It can then be utilized for signal demodulation, decoding, or equalization processes(Chiueh and Tsai, 2008) .This section provides a comprehensive overview of several channel estimate strategies that have been effectively developed. The key ways for handling the problem of channel estimation are decision directed, pilot aided, semi-blind, and blind methods.The subsequent subsections provide an overview for each class.

3.1 Estimating the channel using decision-directed techniques.

This technique utilizes training symbols in conjunction with the detected symbol during the estimation procedure.(Hanzo et al., 2010) Figure 2 depicts a channel estimator model that utilizes a decision-directed approach. Examining the a posteriori channel transfer function is of utmost significance. The initial value can be determined based on the available detected symbols and the current incoming data. During the subsequent time slot and throughout the demodulation phase of the next received symbols, the previously determined a posteriori channel transfer function is used as an a priori channel estimate Further information on the functioning of the block diagram illustrated in Figure 2 can be found in reference(Madni et al., 2014) .The key aspect of this technique is the necessity of use small pilot symbols to initiate the channel estimate process.

3.2. Pilot-Assisted Channel Estimation

The training-based method is a conventional approach used to estimate wireless communication channels. The symbols that are sent are combined with training sequences that the receiver recognizes at a specific place before transmission. Training symbols are used at the receiver end to estimate the channel state information (CSI) by taking into account their placements [22].

3.3. Estimating the channel using semi-blind and blind techniques.

Training symbols are not necessary in this technique. Instead, the observed received signal, which is the sole measurable signal, is utilized to estimate channels by providing information on the features of the transmitted signal and its intrinsic characteristics. The blind strategies can be categorized as statistical approaches that use the periodic features of received signals and deterministic methods that make assumptions or take into account channel parameters and received signals with deterministic values(Petropulu et al., 2004) . The literature contains references to blind channel estimate techniques employing deterministic and statistical methods for single antenna OFDM communication systems . The process of blind channel estimation is depicted in Figure 6.

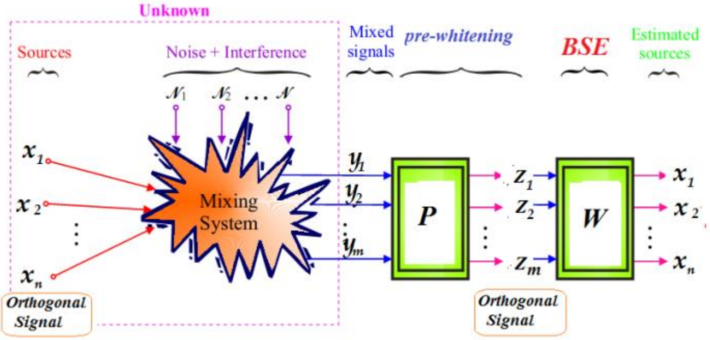

Figure 6: displays a straightforward block diagram illustrating the method of blind channel estima tio.

4.Active areas in current channel modeling

4.1. Air-Ground, Air-Air, and V2X Channels Mobile-to-Mobile Channels

Several organizations have collaborated on diverse communication methods for automobiles. The IEEE 802.11p standard was created specifically for establishing communication networks between vehicles (V2V) and between vehicles and other entities (V2X). In a similar vein, NASA and other organizations have been developing novel aviation communication systems for unmanned aerial vehicles (UAVs) and advanced air mobility and urban air mobility passenger and freight missions. These applications may involve platforms that move quickly, such as mobile-to-mobile connections, resulting in rapid changes in the channel that need to be accurately represented. These fluctuations can arise from both multipath propagation and obstruction, as well as vehicle dynamics and shifting platform attitude(Thielecke et al., 2023).

4.2. Millimeter-Wave and THz Band Channels

In the pursuit of achieving faster wireless data speeds, carrier frequencies have consistently risen to accommodate the utilization of wider channel bandwidths. Cellular networks have started utilizing millimeter wave (mmWave) frequencies for achieving data rates of Gigabits per second (Gbps).

Higher frequencies result in greater channel attenuations or route losses, thereby necessitating the use of directional antennas, which poses challenges for mobile applications. Models for wideband channels must incorporate the unavoidable dispersion that occurs in all situations, except for the most basic ones. THz frequencies offer even greater bandwidths, albeit with shorter link ranges. These frequencies are commonly used indoors for data centers and intra-computer links(Zajić, 2023).

4.3. Satellite Channels and Atmospheric Effects

Satellite communication systems are currently striving for greater data rates and improved reliability.In this context, it is necessary to ensure power efficiency for long link distances, as well as accurately quantify atmospheric attenuations caused by clouds and rain in order to properly account for them. Even terrestrial settings, including tropical environments, have substantial atmospheric impacts such as severe storms. There is evidence indicating that climate change is worsening these effects(Luini, 2023).

5.Modeling techniques, application and critical channel features.

The wireless channel between transmitter(s) and receiver(s) is a crucial component for achieving successful wireless communication, as it can be prone to loss, distortion, and changes with time. Multiple methods exist to characterize the behavior of the wireless channel. These descriptions are utilized in computer simulations to evaluate the efficiency of communication networks. Computer simulations are generally simpler and more cost-effective than field testing. Field experiments are often conducted after computer simulations have calculated important channel properties like as route loss, dispersion, and Doppler. These simulations can evaluate several communication characteristics, including bit and packet error rates, range accuracy, handover behavior, latency, interference level, system capacity, and coverage(Matolak and Fiebig, 2023).

Despite the growing capacity of computers, it is rare to replicate an entire communication system all at once. This is because of the intricate nature of the system and the need to simultaneously simulate both short-term and long-term characteristics, such as bit error rate and handover rate. Combining these factors would significantly increase the duration of a simulation run.

Simulations, on the other hand, focus on particular features and therefore necessitate concise explanations of the channel behavior. Therefore, there are different categories of descriptions available, which include just statistical explanations of long-term deterioration factors, the progression of multipath elements, and the frequency of shadowing incidents. Certain models are based on theoretical foundations and exhibit a deterministic aspect. For instance, the Friis' transmission model predicts the expected received power in single-path line-of-sight links. Additionally, knife-edge models describe the diffraction of electromagnetic waves near the edge of a building. Alternative models utilize geometric arrangements, such as ray tracing. In addition, hybrid models such as deterministic-stochastic models and specialized site-specific models are frequently employed.

Moreover, channel models are highly influenced by the specific carrier frequency employed, the surrounding environment, and the operational characteristics of the transmitter and receiver platforms. In the subsequent subsections, we outline a number of pertinent areas for future research in channel modeling(Matolak and Fiebig, 2023).

5.1.Ray Tracing

Ray tracing is a method that uses high-frequency geometry to accurately represent the behavior of a channel. Ray tracing is a crucial tool for planning mobile radio cell networks due to its ability to analyze coverage and interference. The main difficulty in ray tracing lies in addressing the significant processing load that arises from the need to create precise geometric representations of the environment. Additionally, accurately representing the electrical properties of materials is crucial. Despite the advancements in processing power, this load persists, especially as the scope of interest expands. (Matolak and Fiebig, 2023)contribution addresses the question of whether ray tracing will replace specialized hybrid channel models in the future

5.2 Standardization of Channel Models

Standardization is beneficial for the general adoption of channel models. The ITU is the primary body for providing officially accepted channel models. Nevertheless, it is important to note that not all channel models are included in ITU.The ITU will provide its views on the future requirements in channel modeling.

5.3 Channel Modeling for New Applications

Recently, there has been a growing tendency to utilize communication protocols for the purposes of sensing, range, and localization. This phenomenon is further supported by the utilization of communication signals with a broader bandwidth in modern radio systems compared to the narrower bandwidth of older signals. It is important to observe that the localization performance improves as the bandwidth of a communication signal increases. Some examples of innovative applications include backup systems for terrestrial navigation in global satellite navigation systems for aviation and maritime users, as well as integrated communication and sensing (ICAS). The latter solution integrates broadband communication and radio sensing into a unified system, resulting in bandwidth savings compared to the utilization of two separate broadband systems. Yin will discuss the difficulties associated with channel modeling in integrated communication and sensor systems(Ma and Zhou, 2023).

6.Channel model importance and consequences of inaccurate models

We are progressing towards the development of 6G systems, which will support a range of safety-critical applications that depend on the accurate and prompt transmission of signals. Unlike the majority of mass market applications utilized on cellphones, safety-of-life applications depend significantly on resilient communication. In addition to interference and jamming, certain channel features, such as deep fades and strong multipath components, can significantly and quickly impair the transmission performance. We offer a limited number of illustrations.

The presence of a robust multipath component can result in significant distortion of the received signal, as seen in Figure 1, and can lead to interruptions in the communication channel. An equalizer can effectively reduce the impact of multipath components, and this can be evaluated by computer simulations. Therefore, channel models must be employed to assess the crucial performance of the system. These models should accurately depict the presence of multipath components, which can cause fading and potentially significant temporal jitter. A channel model that is not accurate may falsely indicate significantly higher performance compared to a model that is accurate. We outline two potential ramifications of imprecise channel models for a collision avoidance system: (1) The number of messages received accurately is higher than what actually happens in practice because to the projected very low bit error rate. (2) The number of messages that need to be sent again is lower because of the low bit error rate, which decreases latency. Therefore, a channel model that is not precise may be the cause of overestimating system performance(Matolak and Fiebig, 2023).

It is essential to accurately incorporate all pertinent information of the channel using a suitable channel model.

In addition, it is necessary to take into account infrequent propagation events, such as robust and enduring multipath components that cannot be resolved by the receiver and result in prolonged fading of the dominant or line-of-sight signal. Although a rare propagation event may occur annually, it might have significant repercussions.

The design of safety-of-life applications in satellite navigation already takes into account unusual propagation events, such as large ionospheric delays caused by a solar storm. Counter measures are currently being developed to address these events. The authors emphasize that numerous safety-critical applications depend on radio transmission. Therefore, it is crucial to identify and accurately predict infrequent yet catastrophic propagation events(Ma and Zhou, 2023).

7-Disscussion and Comparison

The key aspect of this technique is the necessity of utilizing small pilot symbols to initiate the process of channel estimation. In their publication(Akhtman and Hanzo, 2005) . Akhtman and Hanzo introduced decision-directed strategies for Code Division Multiple Access (CDMA) systems with Multi-Carrier and Orthogonal Frequency Division Multiplexing (OFDM) systems. The proposed techniques require a channel model that is based on sample spacing. In literature, this model is unsuitable for real-time situations. However, in this case, the decision driven strategy provided by(Akhtman and Hanzo, 2007) .for OFDM systems employing the Recursive Least Square (RLS) algorithm as an adaptive predictor(Schafhuber and Matz, 2005) is expected to be implemented for the channel impulse response in the non-sample spaced model. Nevertheless, the primary disadvantage arises from the computational complexity when the number of subcarriers in an OFDM system greatly exceeds the number of channel paths.

Munster and Hanzoin (Munster and Hanzo, 2002) conducted a study on the performance of an adaptive OFDM transceiver that utilizes modulation mode adaptation and decision driven approaches. The objective of the study referenced in (Li et al., 2002) was to reexamine multiple input-multiple output (MIMO) orthogonal frequency division multiplexing (OFDM) systems with the aim of minimizing inter-antenna interference and inter-symbol interference (ISI). It is assumed that the channels are independent, and the research is focused on using the estimated delay of the channels to estimate channel characteristics. Du and Li (21) utilized a subspace-based decision-directed approach to analyze a MIMO OFDM system. They employed an adaptive filter with low rank. However, when the signal-to-noise ratio (SNR) is low, it is observed that the performance deteriorates due to the presence of intense noise, which leads to errors in tracking the subspace.

Several scholarly publications have focused on the issue of channel estimation using the pilot aided technique. In a previous study, a comparison was conducted between overlaid pilot aided modulation schemes and pilot assisted modulation proposed by a different source. The pilot aided modulation approach was discovered to outperform the overlaid pilot assisted modulation technique in terms of bit error rate (BER). Conversely, with a rapid fading channel, the desired outcomes can be obtained, but this comes at the cost of increased computing complexity.

In their work, Cai and Giannakis (36) introduced a PSAM, an adaptive pilot symbol aided modulation, to address the issue of prediction errors and channel estimation. The research endeavor aimed to enhance spectral efficiency by improving the spacing and power allocation between data symbols and pilots. The authors claimed that the proposed technique operates well, even when there is a significant delay in feedback. The study in (Negi and Cioffi, 1998) examines the Maximum Likelihood (ML) estimator for the OFDM system.

The article in(Chang and Hsieh, 2008) introduced a pseudo pilot technique for detecting data symbols in fast varying channels. This algorithm primarily relies on a regression model based least squares fitting approach. Its key advantage is that it can recognize data symbols without raising the pilot density.

In addition, the authors in (Chang and Hsieh, 2008) introduce a pilot pattern design and an optimal training method for OFDM systems operating over a Rayleigh fading channel. The optimization of pilot-assisted channel estimate is focused on open loop OFDM systems, as shown in (Panah et al., 2008) .Uniform spacing among pilots is considered best. In addition, the Lloyd algorithm and vector quantization are employed to reduce feedback.

Earlier blind approaches rely on the higher order statistics (HOS) of received signals to estimate channel coefficients. The referenced works can be found in (Shalvi and Weinstein, 1990) . They encounter a significant computational difficulty due to the need for a substantial amount of data samples or extensive information. Consequently, researchers utilized second order cyclic statistics (SOS) to create and advance novel blind techniques, as mentioned in references (Tong, 1993) . The channel estimation based blind technique in the frequency domain is introduced in ,while (Delmas et al., 2008) presents the blind estimation of the single input-single output (SISO) FIR channel using the sum of squares (SOS) of transformed data. Necker and Stuber conducted a study on a deterministic blind technique using maximum likelihood estimation for phase shift keying signals. Several scholarly articles have focused on blind estimating methods utilizing subspace schemes in OFDM communication systems(Cai and Akansu, 2000) .A blind channel estimation technique is provided for un-coded orthogonal frequency division multiplexing (OFDM) in (Banani and Vaughan, 2010) . A constrained linear minimal mean square error (MMSE) approach is employed to estimate an initial data symbol for each subcarrier. The authors assert that the proposed blind system is highly advantageous and may be effectively employed for high purposes.

8.Conclusion

The subject of wireless channel and propagation modeling is thriving, thanks to a diverse range of applications being utilized in an increasing number of situations, spanning a wider fraction of the electromagnetic frequency spectrum. Various advanced modeling methodologies, encompassing analytical, computer-based, statistical, and hybrid models, are now under development to address wireless channel modeling across all domains. This paper provides a concise overview of these subjects, accompanied by illustrations of the imperative requirement for precise channel models in numerous forthcoming applications.

This study presents an overview of fading channel and several channel estimate strategies, including decision guided, pilot assisted, blind, and semi-blind procedures. The simple mathematical representation of both variant and invariant multipath CIR models is provided. Despite the high efficiency of blind approaches and the absence of a need for training symbols, the significant negative lies in the substantial computing complexity. As a result, they utilized a time-invariant channel and restricted themselves to a slowly time-variant channel.

Despite its straightforward execution, the pilot assisted technique has two primary disadvantages. The primary limitation, overall, is the inefficient utilization of communication capacity. The second limitation of this technique is its reliance on pilot symbols and data points, which are estimated using interpolation techniques that do not have optimum performance and cannot be established with absolute certainty. Therefore, unsolved mistakes may arise during the estimate operations. Nevertheless, the partially impaired strategies employed for the channel estimation problem exhibit superior performance compared to blind methods and pilot assisted techniques. Ultimately, the decision to use direct channel estimating approaches with their iterative schemes is superior to using semi-blind, blind, and pilot assisted channel estimation techniques.

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