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Propagation Prediction for Wireless Communication Systems

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ABSTRACT: The usage of greater data rates (broader frequency range), propagation in increasingly complicated settings, smart antennas, and multiple-input multiple-output (MIMO) systems are all on the rise in the development of wireless communication. The purpose of this article is to provide a thorough overview of propagation prediction models for terrestrial wireless communication systems. The use of ray-tracing methods to the creation of deterministic propagation models is the subject of this paper, which briefly describes the classic empirical models. It is addressed how to improve computing efficiency and accuracy. Traditional statistical models are also briefly examined to ensure that they are comprehensive. Novel difficulties to propagation prediction are discussed, as well as some new methods for dealing with them. Heinrich Rudolf Hertz discovered the trans- mission of electromagnetic waves in 1886, confirming Maxwell's long-debated predictions of wave propagation. Guglielmo Marconi, who performed his famous experiments from 1894 to 1901, was the first to achieve the first milestone on the path to wireless communications. In 1901, Marconi showed that a radio wave could maintain communication with ships crossing the English Channel.

KEYWORDS: Channel Characterization, Delay Spread, Route Loss, Propagation Prediction Model, Ray Tracing.

1. INTRODUCTION

In the 1930s and 1940s, two-way radio communications and broadcasting systems were created. Bell Laboratories in Holmdel, NJ, pioneered the cellular concept in the 1960s and 1970s. In the 1980s, the first generation of wireless mobile communication systems emerged, which were based on analog technology and FM modulation. The Nordic Mobile Telephone (NMT) [1] and Advanced Mobile Phone System are examples of first-generation cellular systems (AMPS). Second-generation (2G) digital cellular systems were created with different standards in the early 1990s. The Goupe Special Mobile (GSM, now Global System for Mobile Communications) in the United Kingdom, the IS-54/136 and IS-95 in the United States, and the Personal Digital Cellular (PDC) [2] in Japan are all examples. 2G systems have increased spectrum efficiency and speech quality in general.

Wireless communications of the third generation (3G) [3] are presently being developed in many parts of the globe. Multimedia services will be provided by 3G networks, as well as additional needs such as apps and communications "anytime and everywhere". Wide-band and broad-band radio technology will be required to achieve this. International Mobile Telecommunications 2000 (IMT-2000), CDMA-2000, and NTT DoCoMo W-CDMA systems are examples of 3G standards. Despite the fact that the third-generation (3G) systems will go live in 2001/2002 and be fully deployed by 2005, the fourth-generation (4G) systems are presently being considered [4]. The 4G system will offer an all-IP network that will combine and deliver new services, such as broadcast, cellular, cordless, WLAN, and short-range communication systems, among others. Propagation Prediction's Importance

Accurate propagation characteristics of the environment should be understood before executing designs and verifying planning of wireless communication systems. The large-

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scale route loss and small-scale fading statistics are typically represented by two kinds of parameters in propagation prediction. The path-loss information is critical for determining and optimizing the coverage of a base-station (BS) location. Small-scale characteristics typically offer statistical information on local field changes, which allows critical parameters to be calculated to assist enhance receiver (Rx) designs and fight multipath fading. Field measurements, which are time consuming and costly, are the only way to get these parameter estimates without propagation forecasts.

The empirical, theoretical, and site-specific path-loss prediction models may be broadly classified into three categories. The majority of empirical models consist of a set of equations developed from extensive field observations. Empirical models are easy to use and efficient. They're accurate in settings that are similar to the ones where the measurements were taken. The empirical models' input parameters are often qualitative and non-specific, such as a dense metropolitan region, a rural area, and so on. One of the most significant disadvantages of empirical models is that they cannot be utilized in various settings without adjustment, and they are often completely worthless. The empirical model for macrocells [5], for example, cannot be used to indoor picocells. The output parameters are mostly range-based rather than site-specific.

Numerical techniques such as the ray-tracing method and the finite-difference time-domain (FDTD) method [6] are used to create site-specific models. The input settings may be very precise and comprehensive. The high computational cost of site-specific techniques may be prohibitive for certain complicated settings. Physically, theoretical models are developed in ideal circumstances. The over-rooftop diffraction model, for example, is developed using physical optics and assumes homogeneous building heights and spacing. Theoretical models are more efficient than site-specific models, while empirical models are more site-specific. Some statistics, including as rms delay spread, coherence band-width, Doppler spread, and coherence time, are used to describe small-scale propagation characteristics. These variables have a direct impact on the design of Rxs as well as the bit error rate estimates. They also make simulations of communication systems easier and offer performance indicators for service quality (QoS).

1.1.Challenges in Modeling Propagation

Although just one or two of these dependencies will emerge in certain instances, wireless communication channels are fundamentally frequency dispersive, time variable, and location selective. The rapid development of wireless communications has resulted in the adoption of higher frequency bands, smaller cell sizes, and smart antenna systems, all of which complicate propagation prediction. Simple empirical and statistical models are frequently employed with acceptable accuracy in macrocells, since the transmitting antenna is typically located on a high tower. In the case of microcells, and particularly picocells, the transmitting antenna may be less than the average height of the buildings in the affected areas. In this scenario, the geometry of the buildings and terrains will have a significant impact on radio wave propagation, resulting in large shadow areas [7]. The outside radio wave travels via reflections from vertical walls and the ground, diffractions from vertical and horizontal building edges, scattering from non-smooth surfaces, and all other conceivable combinations. There is no universal empirical or statistical model that can be utilized to predict the outcomes of these complex propagation scenarios.

In addition to the typical characteristics like path loss and delay spread, smart antenna systems that take use of spatial diversity need in- formation on the angle of arrival of the multipath. In contrast to traditional systems, where multipath is deemed detrimental, a MIMO system utilizes multipath to offer greater capacity. Space-time and space-frequency channel

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models are used in all of these novel systems. Site-specific models based on ray-tracing methods have been created to cope with the increasingly complicated propagation settings. The primary objective of a simple ray-tracing algorithm is to calculate the trajectory of a ray emitted from a transmitting antenna. The intersection of a ray with a surface (in three-dimensional (3-D) instances) or a ray with an edge segment (in two-dimensional (2-D) cases) is calculated in this method. If the propagation environment is vast and/or complicated, the calculation time may be enormous, even beyond the capabilities of current computers. The most significant impediment to the use of ray-tracing techniques is therefore their computational efficiency. More kinds of rays, such as reflected, transmitted, diffracted, and scattered rays, and their combinations, may be taken into consideration using an efficient ray-tracing process, which improves forecast accuracy. Many factors influence the accuracy of propagation prediction. These include precise understanding of the electric characteristics of walls and other objects involved, as well as exact information of building locations and sizes. Trees, big posts, vehicles, and people in outdoor situations, as well as furniture in interior ones, may all have an impact on the outcome. Because of the need for a more precise forecast of the indoor/outdoor propagation mechanism, proper characterization of complex wall constructions, including metal-framed windows, has recently received attention. Existing prediction methods must be updated and enhanced, and new processes and techniques must be created to address these difficulties.

2. DISCUSSION

2.1. Microcellular Environments Two-Slope Model

This measurement-based approach is used to propagate line-of-sight (LOS) in an urban environment. The model is built on a two-ray propagation mechanism, which includes the LOS ray and the ground refraction ray. This model is characterized by the existence of a break point that clearly distinguishes the various characteristics of propagation in close and distant areas relative to the BS. The slope before the break point is less than two, whereas the slope after the break point is higher than two, according to regression analysis of observed data in the San Francisco Bay region.

2.2. Additional Models

The SBR algorithm is the fundamental process of a ray-tracing approach. The transmitting antenna (Tx) fires a ray, which is then tracked to check whether it strikes anything or is picked up by the receiving antenna. Reflection, transmission, diffraction, or scattering will occur when an item is struck, depending on the geometry and electric characteristics of the object. The electric field (power) associated with a ray is computed when it is received by a receiving antenna. This algorithm has a few basic flaws that must be addressed. The first is learning how to fire a ray. The second question is how to tell whether a ray has struck an item. Third, how is it decided which item is really struck by the beam if there are many potential targets? The fourth question is how to tell whether a ray has been received. Ray launching and reception criteria, as well as ray intersection with an object.

2.3. Ray-Tracing Algorithms Acceleration

The ray-tracing technique [8] is straightforward and extensively utilized in the prediction of site-specific propagation. The ray-tracing technique, on the other hand, may be inefficient in terms of computing. This is why numerous papers have been written on how to speed up ray-tracing techniques. Acceleration may be accomplished in a variety of ways. The initial step is to decrease the number of objects on which the actual ray-object intersection will take place. The second is to speed up the intersection test computation. The preprocessing of the propagation environments and/or the locations of Tx and/or Rx is fundamental to all acceleration techniques. We'll provide a quick rundown of these initiatives in this section.

2.4. Angular Z-Buffer (AZB):

AZB stands for Angular Z-Buffer [9]. This approach is based on the computer graphics light buffer technique. The fundamental concept is to split space into angular sections based on a source point. A Tx or an image of it linked to a reflection plane may be used as the source point. Only those items situated in the angular area enclosing the ray must be checked for ray intersection when a ray is fired from the source point. This technique can speed up the ray-tracing procedure, however it is difficult to preprocess many reflections using this method. This is due to the fact that there are many source points (including the Tx and a significant number of its pictures), each of which requires an AZB.

2.5. Ray-Path Search Method:

The ray-path search algorithm uses the visibility graph to restrict the intersection test, based on the notion that ray-tracing procedures should only be performed to regions where rays are likely to exist. There are many layers in the visibility graph. All things visible to the Tx are in the first tier (for LOS rays). Objects visible to the first layer are in the second layer (for transmitted, re- flected, and diffracted rays). Further levels have a recursive connection as well. Because determining visibility between two items is difficult, acceleration techniques like bounding boxes are used to create a visibility graph. Only the objects in the first layer of the visibility graph must be checked for the initial intersection when a ray is fired from the Tx. Only items in the th layer must be examined to identify the ray's intersection, resulting in a reduction in calculation time.

2.6. Method of Space-Division:

In computer graphics, the space-division technique is extensively employed. The fundamental concept is to construct a grid (typically rectangular) in the propagation environment, then develop a lookup table that registers items in each grid cell. A ray is traced in the grid when it is launched. The lookup table is examined for each grid the ray traverses to determine whether there are any items in the grid. If this is the case, the ray is examined for intersection with these objects. A reflected (or diffracted) and/or transmitted ray will be produced if any item is struck, and the new rays will be tracked further. The space-division technique [10] may provide efficient ray tracing and quick ray traversal. This is because the grid traversal method is quick, and the intersection is only done on a limited number of items. The following subsections will describe two kinds of space-division techniques that have been used to study propagation in urban settings.

3. CONCLUSIONS

Due to the rapid advancement of wireless communications, new concepts and methods for increasing capacity and improving QoS have emerged. To achieve the best design of next-generation communication systems, smaller cell sizes, higher frequencies, and more complex surroundings must be more precisely predicted, and site-specific propagation prediction models must be created. To describe the combined spatio-temporal channel, new methods such as smart antennas and multi-input and multi-output systems need novel propagation prediction models. The state-of-the-art propagation prediction models were reviewed in this article, which ranged from early basic empirical formulae to current site-specific ray-tracing-based models. It is shown that for propagations in complicated settings, the ray-tracing technique may give route loss, time of arrival, angle of arrival, and even certain statistic characteristics. New problems were briefly addressed, as well as new ways for dealing with them. New efforts were emphasized in particular to describe walls of complicated buildings

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and create comparable ray-tracing models for windows and metal-framed structures. These novel developments, in combination with computationally efficient ray-tracing techniques, are anticipated to pave the way for the creation of an integrated indoor/outdoor urban propagation model that considers the complexities of the indoor/outdoor interface.

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