A Review of Wavelets Emerging Applications for Digital Wireless Communication

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Received: 24th July 2022; Accepted:28th December 2022; Published: 30th December 2022

***Abstract*:** The use of wavelets in digital wireless communication systems has benefited data compression, source and channel coding, signal denoising, channel modeling, and transceiver design. During these applications, Wavelet's key advantage its ability to precisely identify signals. This paper discusses recent trends and developments in the use of wavelets in wireless communications. Among other applications, wavelets are employed to model wireless channels, reduce interference, denoise, offer multiple access, transport ultra wideband data, transmit cognitive radio data, and connect wireless networks. Structural performance and architectures that can handle enormous amounts of data have become more challenging as a result of the merging of communication and information technology and the potential for pervasive connectivity. The possibility of pervasive connectivity and the convergence of communication and information technology have made it difficult to create technologies and systems that can handle massive amounts of data while operating with severely constrained resources like electricity and bandwidth. Wavelets are the best solution for this issue. Due to its scalability and versatility, wavelet technology has a bright future in wireless technology.

Index Terms: Wavelets Wireless Communication, Wavelet Applications, Image Compression, Biomedical applications of wavelets

1 Introduction

Wavelet analysis is a relatively new application of mathematics. Fourier analysis cannot provide accurate results in a number of situations due to the non-stationary nature of signals. Wavelet transforms can be employed as a potential alternative in this case.[1] The concept of temporal frequency analysis will also be introduced using the Short Time Fourier Transform (STFT).[2] The Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT) will be explained theoretically using mathematical equations.[3]

Decomposition of 1-dimensional and 2-dimensional signals is explained with appropriate examples, leading to a notion for application. As multimedia applications proliferate, wavelet-based transmission systems are increasingly widespread. Additionally, the advantages of a technique called Orthogonal Frequency Division Multiplexing (OFDM) based on wavelets are highlighted. In biological signal processing, wavelet offers notable performance enhancements ranging from the detection of aberrant regions to a superior feature extraction technique for post-processing. The adoption of effective data compression techniques is required by the production of digital systems and wireless technologies. The EZW and SPIHT algorithms as well as the wavelet transform are discussed. Both college and university students who wish to do research on wavelet and its application will consider the part to be helpful.[4]

In digital cellular systems, the usage of wavelets has been beneficial for compression algorithms, source and coding scheme, signal denoising, channel modelling, and transceiver design. The versatility and ability to correctly detect signals are wavelets' main advantages in all these applications. Wavelets are the best solution for this issue. Due to its scalability and versatility, wavelet technology has great promise for future wireless communication. [5]

We are familiarized with real-world indicators like conversation, a patient's temperature taken hourly, and so on. Typically, signals are shown as a time-domain graph. The same information can be communicated in a multitude of ways in literature, much as signals can be expressed in the frequency response to convey information. These information can be handled based on the application to generate desired outputs or carry out specific tasks.

With advantages like transformation adaptability, less responsiveness to channel defects and interference, and better spectrum use, wavelet transform has lately been proposed as a workable analytic approach for complicated digital communication systems. Among other aspects of wireless communication system design, wavelets are used in channel modelling, transmitter design, information retrieval, processing data, source and encoding, interference mitigation, signal de-noising, and energy-efficient networking. The goal of this study is to assemble the most recent developments and innovations in wireless technology using wavelets and their offshoots, such as wavelet packets. Special importance is given on the uses of transmission technology. It is significant to remember that this study does not aim to provide an exhaustive analysis of all relevant literature.[6]

2 Background of in Wavelets wireless communications

Wavelets have been used in digital wireless communication for several decades. The use of wavelets in this context can be traced back to the early 1990s, when they were first introduced as an alternative to other signal processing techniques, such as Fourier analysis.

One of the early applications of wavelets in digital wireless communication was in the development of efficient coding schemes for data transmission. Wavelets have also been used for channel equalization, channel estimation, and interference cancellation in wireless communication systems.[7]

In recent years, wavelets have gained increasing popularity in digital wireless communication due to their ability to represent signals with sharp transitions, their robustness to noise, and their low computational complexity, the usage of wavelets has been beneficial for compression techniques, source and coding scheme, signal wavelet transform, channel modeling, and transceiver design. . They have been applied to a wide range of wireless communication systems, including cellular networks, satellite systems, and wireless local area networks (WLANs).[8]

The flexibility and capacity to properly identify signals are wavelets' main advantages in these applications. This study discusses current advancements and trends in the use of wavelets in wireless technology. In wireless channel modeling, interference reduction, and denoising, scrutinized Wavelets are frequently utilized. OFDM modulation is used in a variety of applications, including multiple access, wireless networks, cognitive radio, and Ultra Wideband communications. Developing large networks and architectures with data while utilizing constrained resources like electricity and bandwidth has become challenging due to convergence of communication and information technology and the potential for pervasive connectivity.Wavelets are the best solution for this issue. Because of its scalability and versatility, wavelet technology has a bright future in wireless communication. [9]

Over the last decade, wavelet application in several domains of signal processing has been a major study topic. Using this technology to compress two-dimensional signals like digital photographs, on the other hand, is rather recent. The most significant benefits of wavelet compression over earlier compression techniques are its adaptability for error protection and its capacity to precisely terminate the compressed bit stream in order to achieve a specific bit rate for transmission. In this research, several of the most modern wavelet coding algorithms for images will be examined, with a focus on the utilization of wireless channels. Images got Images have noise images haveThese techniques noise in them. There are some Techniques for filtering the images that have been altered, as well as these techniques can restore images that have been degraded by the interference of noise, are among these developments. [10]

Overall, wavelets have proven to be a powerful tool for digital wireless communication, offering a number of advantages over other signal processing techniques and finding a wide range of applications in this field.

2.1 Signal Analysis with Wavelet Representation

We present a very quick explanation to the wavelet transform idea and wavelet transforms in this part, as well as a few properties that are relevant to communication system design. [6–16] provides a full examination of the topic

2.2 Wavelets and wavelet transforms

Ondelette, which translates to "small wave," was first used by a French academic by the name of Jean Morlet [6]. The term "wavelets" was later created by changing "onde" to "wave" in the English translation. Wavelets are, as their name implies, small waveforms with a predetermined oscillation pattern that really is non-zero for just a finite amount of time (or space) and additional mathematical properties. An input signal is split into multiple frequency components using the wavelet transform, which then analyses each component with resolutions that are appropriate to its scale. Although sines and trigonometric functions are the foundation functions, the Fourier transform also breaks down data into fundamental waveforms. The wavelet transform has excellent time resolution but poor frequency response at high frequencies, and good frequency resolution but weak time resolution at low frequencies. This method makes sense when the signal has high frequency components that are present for brief times and lower frequency components that are present for longer periods. Fortunately, most engineering applications encounter signals of this kind.[11]

2.3 TRANSFORMATION OF WAVELET PACKETS

The wavelet packet transform, in contrast to the wavelet transform, breaks down even the higher frequency bands that the wavelet analysis doesn't break down.The wavelet packet decomposition process is shown in Figure 4. S stands for signal, whereas A and D stand for approximations (Frequency which is higher in terms) and decompositions, respectively (frequency which is low in terms).

3 A Wavelet-based approach in wireless communications

Wavelets and wavelet packets have a number of advantages in wireless communication systems. We'll go through a couple of the advantages of wavelets here:

3.1 Semi-arbitrary division of the signal space and multirate systems

Subcarriers with varied bandwidths and symbol lengths can be created using the wavelet transform. Because each transmitted signal has the similar time and frequency plane surface, increasing bandwidth (or decreasing bandwidth) results in decrease and increase in subcarrier symbol length. A multirate system can be built using the properties of the wavelets. Such a capability is advantageous from a communication standpoint for systems that must accommodate numerous data streams with differing transport delay requirements.[12]

3.2 Flexibility with time-frequency tiling

Another feature of wavelets is their ability to organize time-frequency tiling in such a way that channel disruptions are minimised. The effect of noise on the data can be minimised by flexibly coordinating the time-frequency tiling. Rather than waiting until the receiver to cope with known channel disturbances, at the transmitter the wavelet-based systems can control it. As a result, they can improve wireless systems' quality of service (QoS).

3.3 Signal or waveform diversity

Wavelets give the physical aspects of diversity currently utilised, particularly space, frequency, and time-diversity, an additional dimension – "Waveform diversity." In a cellular communication network, signal diversity, similar to more and more systems, could be used to minimise inter-cell interference by assigning distinct wavelets to nearby cells. Other example is the Ultra Wideband (UWB) communication system, which allows users to share a very large band with minimal interference by cleverly transmitting pulse waveforms.

The mother wavelet function is the (inverted) impulse response of a continuous- or discrete-time bandpass filter. A continuous- or discrete-time wavelet bandpass filter that implements one (for example, dyadic) scale of the multi - resolution wavelet transform can be used to construct the discrete wavelet transform.[13]

4 Advantages Of Wavelet In Digital Wireless Communication

Wavelets have several advantages for digital wireless communication:

1. Compactness: Wavelets can be used to efficiently represent signals with sharp transitions, such as those found in many wireless communication systems. This allows for a more compact representation of the signal, which can be transmitted more efficiently over the air.
2. Robustness to noise: Wavelets can be designed to be highly resistant to noise, making them well-suited for use in noisy environments such as wireless communication channels.
3. Multi-resolution analysis: Wavelets can be used to perform multi-resolution analysis, which allows for the signal to be analyzed at different scales. This is useful for wireless communication systems, as it allows for the signal to be analyzed at different levels of detail depending on the needs of the application.
4. Time-frequency localization: Wavelets have good time-frequency localization properties, which means that they can be used to accurately represent the frequency content of a signal over a particular time interval. This is useful for wireless communication systems, as it allows for the signal to be accurately analyzed over a specific time period.
5. Low computational complexity: Wavelets can be implemented with relatively low computational complexity, making them suitable for use in real-time communication systems.

5 Disadvantages To Using Wavelets For Digital Wireless Communication

There are a few potential disadvantages to using wavelets for digital wireless communication:

1. Complexity: While wavelets can be implemented with relatively low computational complexity, they can still be more complex to work with than some other signal processing techniques. This may make them less suitable for use in systems with limited computational resources.
2. Limited frequency resolution: Wavelets may not provide as much frequency resolution as some other signal processing techniques, such as Fourier analysis. This may make them less suitable for applications that require high-resolution frequency analysis.
3. Limited time resolution: Wavelets may not provide as much time resolution as some other signal processing techniques, such as short-time Fourier transform. This may make them less suitable for applications that require high-resolution time analysis.
4. Limited adaptability: Wavelets are generally not as adaptable as some other signal processing techniques, such as filter banks. This may make them less suitable for use in applications where the signal characteristics are constantly changing.
5. Limited support for linear operations: Wavelets are not well-suited for performing linear operations on signals, such as filtering or convolution. This may make them less suitable for use in applications where these types of operations are required.

6 Applications Of Wavelets In Wireless Communication

6.1 Image Compression

The process of lowering the size of a digital image in bytes without affecting image quality is known as image compression. Because of the reduced file size, more images can be kept in a set quantity of disc or storage. It also reduces the amount of time it takes to upload or download photographs over the Internet.[14]

Pictures can be compressed using a variety of techniques. The two most common compression graphic files to be used on the Internet are JPEG and GIF. The JPEG method is more popular for pictures, while the GIF technique is more popular for line drawings and other graphics with simple geometric shapes.

Because the data link on a wireless system node consumes a significant amount of power, a data compression strategy can be employed to limit the quantity of data shared in a network, resulting in power savings. The higher the data compression ratio, the greater the power savings percentage.[15]

6.2 Radar

Radial velocity and angle are calculated by using radio waves to gauge a distance (range tendency), angle, or radial velocity of an object in relation to its location through the use of radar (radio detection and ranging). What are the most common applications of RADAR? Military, enforcement agencies, space travel, sensing, airplane navigation, ship navigation, and air traffic controllers all employ RADARs.

Filtering undesirable data with wavelets would be difficult since disturbances can significantly affect ground penetration radar (GPR) signals, regardless of the fact that several solutions have been presented. Because of signal degradation at low altitudes, noises are gathered by probes, particularly from deep sites, but they may mask reflections. In order to extract valuable minerals based on information received from underground, data analysis is necessary in a range of technical fields.The use of wavelets is discussed in this study as among the most essential data analysis methodologies. Wavelet analysis of GPR signals, on the other hand, would be problematic. When it comes to de-noising and evaluating signals, remembering the wavelet function, decompose level, threshold estimation, and threshold transformation is critical; they must be chosen with care, as they have a big impact on the results if not properly designated. Multiple wavelet functions are used to conduct de-noising and restoration on synthetic noisy signals created mostly by finite-difference time-domain (FDTD) technique to account for the most suited function for the task. Many different decomposed levels, threshold estimation methodologies, and threshold modifications are investigated during the denoising operation. Actual statistics from a diversity of antenna frequencies widely utilised in engineering is also used to identify the optimal wavelet analysis.

6.3 Earthquake Prediction

The field of earthquake prediction aims to determine the timing, Seismology's field of earthquake prediction aims to pinpoint the timing, area, and intensity of upcoming quakes within certain bounds, with a focus on "determining characteristics for the next large earthquake to occur in a region. As the emphasis on attaining seismic design increases, there is an immediate need for appropriate ground shaking measured for use in highly nonlinear analyses. However, it is typically not possible to obtain a suitable recorded time history that is proportionate to the assessed risk at a particular site. The development of the ground shaking prediction models is based on a statistical analysis of the observed seismic activity for a variety of source and site factors in order to meet this need. The ground motion time history is then constructed, if necessary, to be compatible with this predicted response spectrum. The ground motion prediction models are frequently built to simulate the frequency response amplitude and frequency at a wide range of natural periods.

These simulated time histories usually lack the wave arrival and the temporal change in the distribution systems according to frequency. For the purpose of immediately creating ground motion time histories that are congruent with a fictitious earthquake situation at a location, researchers present a wavelet-based earthquake ground prediction model.[16]

7 Biomedical Applications Of Wavelets

This section is meant to supplement, which provides a general overview to the WT. Its goal is to reevaluate some of the material's features in light of biomedical applications. In a practitioner's perspective, Wavelet based transform (CWT or wavelet frames) and nonredundant wavelet frames are the two different types of wavelet decomposition (orthogonal, semi-orthogonal, or biorthogonal wavelet bases). Because it provides a shift-invariant description, the first kind is frequently employed for signal analysis, feature extraction, and test automation; it is particularly important for such a range of applications. The second type , on the other hand, is clearly more nearly suitable whenever some sort of data reduction is desired or if the orthogonality of the image is crucial. Due to computational concerns, however, the choice between these two solutions is not always clear. Even when employing the fastest available algorithms, aUsing Mallat's rapid technique, decomposition in respect of wavelet bases is typically much quicker than a redundant analysis[17]. There is a cost-benefit trade-off for the first class of problems, and many researchers have looked into non redundant wavelet decomposition methods and found them to be highly effective.

7.1 Biomedical signal processing

We'll go over each of the biological subjects in detail after reviewing the WT's main characteristics. We'll begin with the most basic physiological signs (1-D processing)

7.2 Bio-Acoustics

Mechanical vibrations caused by the heart's pumping can be detected with a stethoscope as pulses or sound. By inserting a microphone through a tube or a catheter into the esophagus or the heart, good quality recording of these noises can be acquired. Even if ultrasound is gradually taking over this diagnostic tool, examination of heartbeats could provide useful information on the pattern of heart activity. Heart noises and murmurs are two types of auditory occurrences that occur in the heart. Sound is a brief, impulse-like event that signals different hemodynamic stages. Murmurs are a symptom of cardiac disease, such as aortic stenosis or valve abnormalities, and are generated by blood flow turbulence.[18]

7.3 Electrocardiography (ECG)

The ECG signal describes the change in the electrical potential measured between electrodes placed on the body during the cardiac cycle. Various sections of the cardiac muscle contract in response to an action potential propagating within the heart, giving the signal its distinctive form. Internal excitement begins in the sinus node, The P wave of the ECG is produced by the extension of the sinus node, which acts as the heartbeat, to the atria. The QRS complex is then produced when the cardiac excitement reaches both ventricles (ventricular depolarization). After being fully activated, the ventricular depolarizes in reaction to the T wave of the ECG (ST phase of the EEG). Their automatic detection is important for diagnosis, as is the timing.[19]

Wavelet signal processing is different from other signal processing methods because of the unique properties of wavelets. For example, wavelets are irregular in shape and finite in length. Wavelet signal processing can represent signals sparsely, capture the transient features of signals, and enable signal analysis at multiple resolutions.[20]

8 Future Directions

Analysis/synthesis wavelet transform configuration, also referred as sub - band or wavelet transform, based electronic image / video processing, has aroused attention in the sector due to its ideal multiresolution representation properties for visual signals.

As a result, early research on the subject was motivated by subband coding, which has been extensively discussed in the literature. Theoretically, prominent multicarrier modulation techniques like orthogonal frequency division multiplexing (OFDM) and cdma access (CDMA) communication systems can be built using a transmultiplexer, a synthesis/analysis filter bank arrangement.

Assessment filter bank design, often referred to as sub-band or wavelet transform-based electronic image/video processing, has aroused interest in the industry because of its capacity to represent signals in a variety of resolutions.

As a result, sub - bands coding, which was extensively documented in the literature, served as the primary inspiration for early research activity on the topic. Similar to this, a so transmultiplexer, a synthesis/analysis filter bank configuration, offers a theoretical framework for analyzing and designing well-liked multicarrier modulation techniques, such as code division multiple access (CDMA) communication systems techniques and orthogonal frequency division (OFDM).

9 Conclusion

In wireless communications, wavelets have a wide range of uses, such as source and coding scheme, transceiver design, wireless physical network transmission, and higher levels. Wavelets' ability to characterize signals with adjustable time-frequency resolution is a crucial component for many applications. This article aimed to provide a comprehensive overview of wavelet-based wireless communications applications, highlighting the numerous opportunities wavelet-based methods provide. The dream of ubiquitous communication is becoming a reality with the convergence of data, video, entertaining, and wireless communications. To make this a reality, systems and technologies that can manage enormous amounts of data within rigorous resource constraints, like those imposed by electricity and bandwidth, must be created. Wavelets are the best solution for this issue. They have the particular advantage of being general-purpose schemes that may be modified to satisfy the various needs and constraints of advanced mobile communications systems. Wavelet technology's flexibility cannot be completely leveraged with present systems and technologies. As a result, wavelet technology is expected to be a strong contender for next-generation wireless networks.

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