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Wavelet diversity: a novel antenna diversity scheme for multipath fading channel.

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Abstract*: Communication over wireless channels is faced with bandwidth and power limitation. Propagation over these channels is filled with challenges like fading, Inter symbol and Co-Channel interference. Fading is moderated by channel coding, Interleaving and antenna diversity techniques. Frequency, Time and Space are some of the diversity schemes used in antenna transmission and reception process. The paper presents a brief introduction on diversity fading mitigation techniques and introduces a new novel diversity scheme based on wavelet transforms: Space wavelet, Time wavelet, and Frequency wavelet diversity.

***Index Terms*: wavelet, diversity, Fading, Rayleigh channel.**

I. INTRODUCTION

Cellular-Mobile technology landscape has seen an exponential growth in India since the beginning of the new millennium. The transformation of an luxury service to common need has changed not only changed the life style of an ordinary Indian but also the socio-economic condition of the society at large. The 2G standard offered basic voice service but also supported other services like fax, data and messaging services [1]. The 3G offered better data rates, Bandwidth, performance and throughput. The 4G technology envisages integration of voice, data and multimedia traffic on a single (IP) Internet Protocol based core network. Along with the rapid increase in technological growth, the service provided by the service providers has also increased in quantity and quality. The competition among the service providers kept the service cost reasonably low. The low service cost synchronized with hardware cost; mobile devices are fast becoming faster, slimmer, smaller, and cheaper. The computing ability of these devices has transformed the desktop to a handheld palmtop.

The wired medium provided a guided and reliable connection between two terminals. The wired medium has bandwidth larger than the wireless; a parallel line always did the job. On the contrary the wireless channel is unreliable, has low bandwidth and is of broadcast nature [3]. Radio transmission between transmitter and receiver can vary from (LOS) Line of Sight to (NLOS) Non Line of Sight [4]. The diverse transmission mechanism can be divided into three modes: Reflection, Diffraction and Scattering Fig.2. Reflection occurs when the propagating electromagnetic wave impinges upon an object that is larger dimension than the propagating wave. Diffraction occurs when the radio path is obstructed by a surface that has sharp edges. Scattering occurs when the medium through which the wave travels consists of objects that are small compared to the wavelength of the wave, and the number of obstacles per unit volume is large. Apart from reflection, diffraction and scattering, the transmitted wave is subjected to propagation-path loss in atmospheric propagation and in terminal propagation [5]. The transmitted signal reaches the receiver not only by LOS but also by NLOS, the signal at the receiver arrives by multipath as in Fig.1. Multipath components combine vectorly at the receiver and the resulting phase determines the reception process. The in phase components of the received signals add with each other and the out of phase components cancel each other. The multipath reception of transmitted radio signals leads to fading phenomenon. Fading is defined as rapid fluctuations of amplitudes, phases or multipath delays of a radio signal over a short period of time or travel distance. Fading is caused by multipath propagation and Doppler shift [6]. Doppler shift refers to change of the frequency of the received signal when the receiver moves away or towards the source. The received frequency increases as the source and receiver move towards each other and decreases as they move away from each other. Doppler shift varies with speed and direction of propagation. Multipath reception causes interferences between two or more versions of the transmitted signal which arrive at the receiver at slightly times.

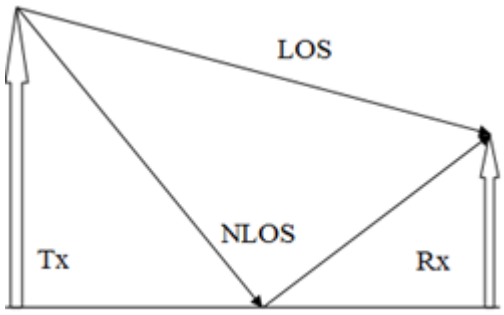

Fig.1. Multipath Reception.

Section II describes fading and Doppler shift in detail. Section III presents a short introduction to antenna diversity techniques. Section IV describes wavelet transform in brief. Section V illustrates a novel antenna diversity scheme called as wavelet diversity. Section VI concludes the paper.

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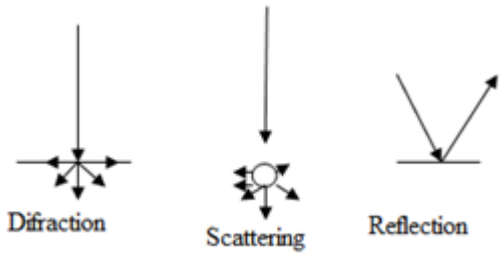

Fig.2. Signal Transmission Mechanisms

II. FADING

Fading is the randomness of signal attenuation; this randomness affects the error probability and capacity of transmission over channels. The receiver receives multiple copies of the same message signals from many sources other than the transmitter. The multipath reception is characterized by three effects, Path Loss, Shadowing and Fading Loss [7]. Path loss is the signal attenuation is due to the fact that the power required by an antenna decreases as the distance between transmitter and receiver increases. Shadowing loss is due to the absorption of the radiated signal by scattering structures. Fading loss is due to random fluctuations of the received power and is caused by Multipath propagation and Doppler Shift.

Fading is often classified into two, large scale fading and small scale fading [4]. Large scale fading is the characterization of the signal strength when the distance between the transmitter and receiver is large. Rapid fluctuation in the received signal strength over short distance or short time durations are called as small scale fading. The objective o this paper is to analyze the effects of small scale fading and to counter it with wavelet based techniques. Small scale adding is the rapid fluctuations of the amplitudes, Phases or Multipath delays of radio signals over a short period of time or travel distance .Small scale fading is caused by multipath reception and Doppler effect. Multipath delay spread leads to time dispersion and frequency selective fading. Doppler spread leads to frequency dispersion and time selective fading. Time dispersion and frequency dispersion of transmitted signals undergo different types of fading. The types of fading depend on channel parameters like RMS delay spread and Doppler spread; signal parameters like bandwidth and symbol period.

A. Time selective Fading

When a mobile channel has constant gain and linear phase over a bandwidth, which is larger than the bandwidth of the signal, the received signal undergoes flat fading. The received signal strength changes with time due to gain fluctuations and spectral characteristics remain unchanged. The channels are also called as amplitude varying channels or narrowband channels. The statistical measure of range of frequencies over which the channel is flat is called as Coherence Bandwidth.

$$B_s \ll B_c \tag{1}$$

$$\tau_s > \sigma_\tau \tag{2}$$

Where τ_s is the reciprocal bandwidth, B_s the Bandwidth, σ_τ RMS delay spread and B_c is the coherence bandwidth.

B. Frequency selective Fading

Frequency selective fading is due to the time dispersion of transmitted symbols within the channel and induces (ISI) Inter Channel Interference. The channels are called as wide band channels as the signal is greater than bandwidth of channel impulse response.
The condition for undergoing Frequency selective fading is

$$B_s \gg B_c \tag{3}$$

$$\tau_s < \sigma_\tau \tag{4}$$

Depending on the relative velocity difference between the baseband signal and rate of change of channel, the channel is classified as fast or slow fading. Channel impulse response changes rapidly within the symbol duration; coherence time of channel is smaller than symbol period of the transmitted signal.

$$T_s \ll T_c \tag{5}$$

$$B_S \gg B_D \tag{6}$$

The relationship between the various types of fading, Bandwidth, time intervals is given in the following table.

Fading due to multipath Delay spread	
Flat Fading	Frequency Selective Fading
BW of Signal < BW of Channel	BW of Signal > BW of Channel
Delay Spread < Symbol Period	Delay Spread > Symbol Period

Fading due to Doppler spread	
Fast Fading	Slow Fading
High Doppler Spread	Low Doppler Spread
Coherence time < Symbol period	Coherence time >Symbol period
Faster channel variation than Base band signal variation	Slower channel variation than Base band signal variation

Table.1. Multipath and Doppler Fading Characteristics

III. WAVELETS

Wavelets transform a signal from domain to another representation, which presents the signal in a more useful form [2] [8]. Wavelets can simultaneously examine a signal both in time and frequency domain. Wavelets can efficiently analyze aperiodic, intermittent and transient signals. Wavelets represent a windowing technique with variable sized regions [9].

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Wavelet analysis allows the use of long time intervals here low frequency s required and short regions where high frequency is required. Wavelet analyses a time-scale region and has the ability to perform local analysis. Wavelets are capable of revealing aspects of data like trends, breakdown points, and discontinuities. A variety of wavelets are used for signal analysis, choice of a wavelet depends on the application considered. Wavelets are classified in communities like, Dyadic translation, wavelet packets, local trigonometric bases, multi wavelets, and second generation wavelets. Each community is further sub-classified into families; the classical community is further sub-classified as Gaussian, Morlet, Mexican hat, Daubechies maxflat, symlets, coiflets, Bi-orthogonal spline wavelets and complex wavelets. Suitability of a wavelet for an application depends on the match between shape of the wavelet and signal. An exact match at a specific scale and location gives a large transform and mismatch gives a low transform. Like Fourier, wavelet transforms can be represented as Continuous and Discrete wavelet. The transform process is computed at various locations and scales of the wavelet; if the process is done in a smooth and continuous fashion then the transform is called as (CWT) Continuous Wavelet Transform, if the scale and position are changed in discreet steps, the transform is called (DWT) Discrete Wavelet Transform.

IV. DIVERSITY

Diversity is a form of redundancy [10]. Transmitting several replicas of the same message simultaneously over independent fading channels constitute transmit diversity. The fading channels are random in nature and highly uncorrelated with one another. If one channel undergoes severe attenuation due to fading, another channel may have a strong signal [11]. Under fairly general condition, a channel affected by fading can be turned into (AWGN) Additive White Gaussian Noise channel by increasing the number of diversity branches. Diversity provides a good likelihood that at least one of the received signals will not be severely degraded by fading. Diversity schemes that mitigate the effect of multipath fading are called as micro diversity; techniques that mitigate the effects of buildings and objects are called as macro diversity [12]. Some of the prominently used diversity schemes are Frequency diversity, Time diversity, Space diversity, and Polarization diversity. Frequency diversity, the message signal is transmitted using several carriers that spaced sufficiently apart from each other to provide an independent fading version of the signal. Time diversity, the same message is transmitted in different time slots, with the spacing between successive time slot being equal to or greater than coherence time of channel. Space diversity is provided by an antenna array. In antenna array the number of antenna elements is spaced so as to provide independent fading path for each antenna. In Polarization diversity two antennas transmit the same signals with two different polarizations. The waves follow the same path and fade differently.

V. WAVELET DIVERSITY

The wavelet diversity can be implemented by a combination of (OFDM) Orthogonal Frequency Division Multiplexing (IEEE 802.11a) and (MIMO) Multi Input and Multi Output antenna system. OFDM combines the three transmission principles of Multi-Rate, Multi-Symbol and Multi-Carrier modulation [13]. OFDM splits a high data rate stream into a number of lower rate schemes that are simultaneously transmitted over a number of subcarriers. The subcarriers are made orthogonal to each other and the spectra of subcarriers are overlapped for bandwidth efficiency. In Practice Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) are used for implementing these sub-carrier signals. A key concept in diversity technique is diversity order is defined as number of independent channel branches. The MIMO system has M Tx and N Rx antennas; there is MN independent channels through which replicas of the same data can be transmitted. Apart from diversity MIMO offers Multiplexing gain, diversity gain, array gain and interference suppression gain.

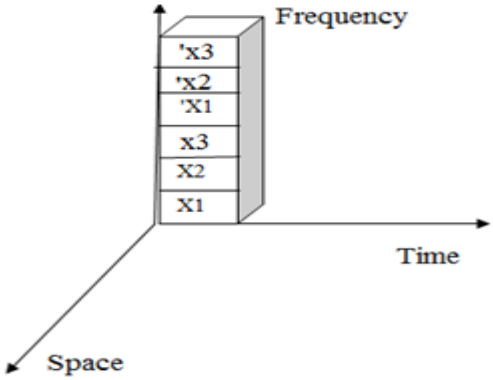

Fig.3 Frequency Diversity

The block diagram of a wavelet based OFDM with MIMO antenna system is illustrated in Fig.7. The proposed wavelet based schemes namely; wavelet-time diversity, wavelet-frequency diversity, wavelet Space-time diversity, and wavelet Space-frequency are exemplified in Fig 3-6 [14]. X1, X2, X3 are symbols of alphabet X obtained from Discrete wavelet transform 1 (DWT 1) and 'X1,'X2,'X3 are the same symbols of X obtained by a different wavelet family Discrete wavelet transform 2 (DWT 2). X1 and 'X1 are uniquely decoded by Inverse Discrete Wavelet Transform IDWT 1 and IDWT 2 respectively at the receiver end.

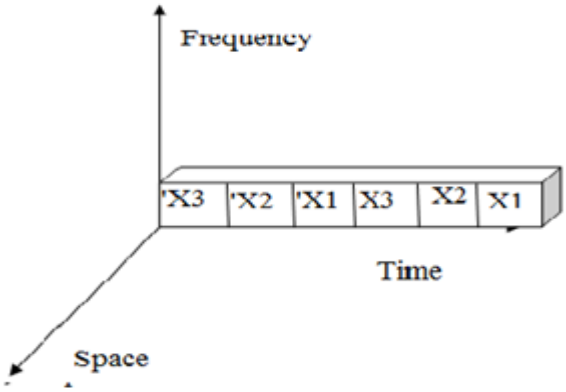

Fig.4. Time Diversity

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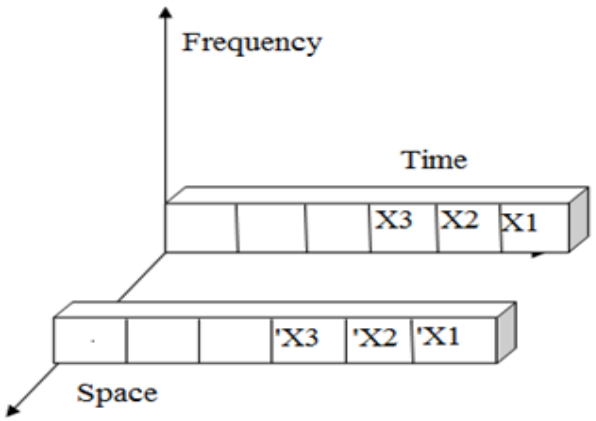

Fig.5. Space Time Diversity

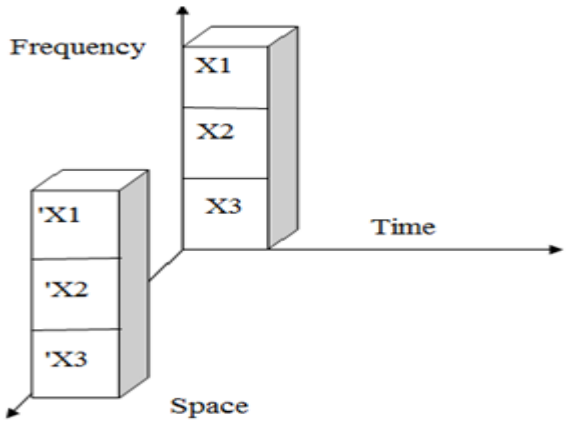

Fig.6. Space Frequency Diversity

A. Wavelet-Time Diversity

The partial system model and diversity scheme is illustrated in Fig.8 and Fig.4. The modified IEEE 802.11a has two wavelet blocks, DWT 1 and DWT 2 and X and Y are the alphabets to be transmitted. The alphabets are transmitted by a transmitter with Single Antenna system. Multiple receivers may be used to receive the transmitted signals.

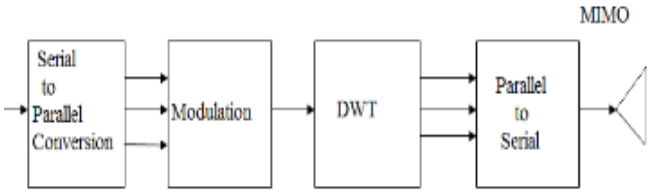

Fig.7. Wavelet based OFDM with MIMO Antenna System

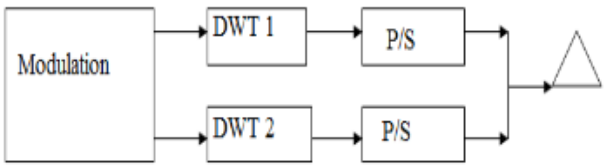

Fig.8. Single Input Antenna for Wavelet-Time Diversity

In a conventional system with single input antenna the symbols of the alphabets X and Y are transmitted as X3, X2, X1, Y3, Y2, Y1 at time t equal to T seconds and the same symbols are transmitted at time T+Δt seconds. Where Δt is greater than or equal to coherence time of the channel. The WOFDM repeats the symbols as X3, X2, X1, ‘X3, ‘X2, ‘X1, Y3, Y2, Y1, ‘Y3, ‘Y2, and ‘Y1.

B. Wavelet –Frequency diversity

The system model and the diversity scheme are shown in Fig.9 and Fig.3. The symbols of the alphabets X and Yare transmitted as X3, X2, X1, ‘X3, ‘X2, ‘X1, Y3, Y2, Y1, ‘Y3, ‘Y2, ‘Y1 at a frequency f1 and the same symbols are transmitted at another frequency f 2 both at the same time T seconds.

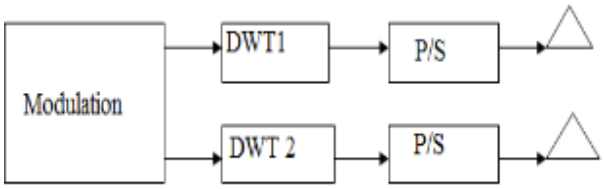

Fig.9. Multiple Input Antenna for Wavelet-Frequency Diversity

OFDM on the other hand transmits the symbols X3, X2, X1, Y3, Y2, Y1 in two frequency bands f1 and f2 both at time T seconds.

C. Wavelet Space Time Diversity

Space diversity is implemented by sufficiently separated multiple antennas (more than 10λ). The spaced multiple antennas can again transmit the signals in time and frequency domain. The System and the scheme are illustrated in Fig.10 and Fig.5.

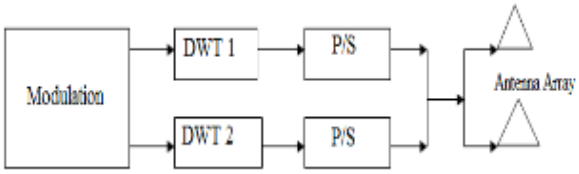

Fig.10. System for Wavelet Space Time Diversity

The system transmits X3, X2, X1, Y3, Y2, Y1, ‘X3, ‘X2, ‘X1, ‘Y3, ‘Y2, ‘Y1 symbols at a frequency f1 and the same symbols are transmitted by an another antenna operating at frequency f 1 at time T and T+Δt seconds . OFDM transmits X3, X2, X1, Y3, Y2, Y1 symbols at time T and T+Δt seconds.

D. Wavelet Space Frequency Diversity

The System and the scheme are illustrated in Fig.11 and Fig.6. The system transmits X3, X2, X1, Y3, Y2, Y1, symbols at a frequency f1 and ‘X3, ‘X2, ‘X1, ‘Y3, ‘Y2, ‘Y1 are transmitted by an another antenna operating at frequency f2 at same time T seconds. OFDM transmits X3, X2, X1, Y3, Y2, Y1 symbols at frequencies f1 and f2 at time T seconds.

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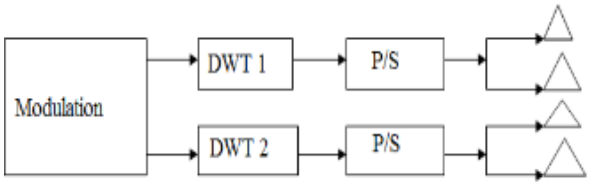

Fig.11. System for Wavelet Space Frequency Diversity

VI CONCLUSION

The diversity order, power and bandwidth are the characteristics considered for the analysis of the diversity schemes and are tabulated in Table.2. It may be noted that for the same number of antennas the diversity order is always higher for WOFDM than the conventional OFDM. Power requirement seems to be the only trade off issue for WOFDM; however increased power fails to improve the diversity performance in case of OFDM. The WOFDM always provides more diversity order or number of independent adding paths. The signals fade differentially and reach the receiver more efficiently.

	Time	Frequency	Space-Time	Space-Frequency
No of Antennas-OFDM	1	2	2	2
No of Antennas-WOFDM	1	2	2	2
Diversity order-OFDM	2	2	2	2
Diversity order-WOFDM	4	4	4	4
Power-OFDM	200%	200%	200%	200%
Power-WOFDM	400%	400%	400%	400%
Bandwidth-OFDM	100%	200%	100%	200%
Bandwidth-WOFDM	100%	200%	100%	200%

Table.2. Comparison of OFDM-WOFDM Performance Characteristics

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