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INVESTIGATION OF DOPPLER EFFECTS ON HIGH MOBILITY OFDM-MIMO SYSTEMS

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ABSTRACT

The merging of Orthogonal Frequency Division Multiplexing (OFDM) with Multiple-Input Multiple-Output (MIMO) systems is a promising mobile air interface solution for the next generation wireless local area networks (WLANs) and 4G mobile cellular wireless systems. The main aim of this research is to design a highly robust and efficient OFDM-MIMO system to support permanent accessibility and high data rates to users moving at high mobility and speeds up to 300km/h. The paper discusses a comprehensive literature review focused in both technologies and the contributions that have been anticipated during the last years, followed by a research project planning with discussions and what experiments will be carried out using the simulation programs. Furthermore, building the hybrid architecture involves merging the novel model with High Altitude Platform system (HAPs) technology, to analyze the overall performance of the network in delivering IP-broadband services and high load application to users.

Keywords OFDM, MIMO, Multi-user, coding schemes, Channel Estimation, HAPs, Doppler velocity

1 INTRODUCTION

Society today is demanding more mobility and accessibility to different aspects of telecommunications systems as well as the demand for ever higher data rates in transferring all kinds of data. The main key role in wireless radio technologies is focused on the effective bandwidth availability given that the spectrum is limited and this stimulates researchers and engineers to use the spectrum more efficiently. One idea was to use various multiple access methods (MA) with the following resources: Frequency; Time; Code and Space leading to the MA techniques beginning with Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Space Division Multiple Access (SDMA), and Orthogonal Division Multiple Access (ODMA) [3], which is one of the major parts of this research. Many combinations of these MA have been used in many communication systems until now and new methods have been developed that allowed MA techniques to be used more effectively. One of them was the use of multiple antennas in both sides of communication network (transmitter and receiver). The purpose of merging new technologies is to find a new system that will overcome all of channel obstacles that wireless networks suffers from. The problem appears clearly when subscribers travel in long or even short distances; it is noticeable that each time discontinuity of data transmission occurs due to failure of terminal connection or fading signal reception, causing the mobile device (laptop or mobile phone) to have errors and system crashes which ends up with wasting battery power and valuable time. This paper proposes an alternative OFDM-MIMO transceiver model that can cope with these changes. It does so with the help of HAPs technology that will hold the new communication payload floating above airline paths as a base station (BS) hanging in the sky, tracking and delivering IP-broadband services to high mobility users along their destinations. This leads to reducing the numbers of BS and power pumped to the surrounding environment and increasing both capacity and coverage area.

2 LITERATURE REVIEW

The fast growth in OFDM-MIMO technology has led to a much wider diversity of applications. The new air-interface technology has become a popular technique and has been adopted in several wireless standards and used in a lot of applications such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), WiMAX networks, Local Area Networks (LAN) standard, Metropolitan Area Network (MAN) standard, and as a potential candidate for the fourth generation (4G) and upcoming generations of mobile phone communications [2]. Integration of OFDM and MIMO has shown a number of advantages and has attracted large interest. New wireless and mobile techniques with advanced source and channel encoding, as well as various smart antenna techniques such as Ultra Wideband (UWB), Space Division Multiple Access (SDMA), and beam-forming [3] are being investigated. Current research is focused on developing the wireless broadband communication systems to deliver high bandwidth broadband services and applications requiring data rates beyond 120 Mbps. Such high data rates require a reduction in channel impairments which requires additional enhancement and improvement to the system architectures.

2.1 DEVELOPMENT OF OFDM

The history of Orthogonal Frequency Division Multiplexing (OFDM) goes way back to the mid 1960's when Chang [4] published a paper with the title "Synthesis of band-limited orthogonal signals for multi-channel data transmission". This paper presented a new principle of transmitting signals simultaneously over a band-limited channel without Inter-Channel Interference (ICI) and Inter-Symbol Interference (ISI). Then came another paper presented in 1967 by Saltzburg [5] showing the performance of an efficient parallel data transmission systems that concentrated on minimizing the crosstalk between neighboring channels. This paper proved visionary today with the technique being used in the digital baseband signal processing against ICI. OFDM has become popular these days using multi-carrier modulation technique when transmitting signals through noisy channels. OFDM has developed into popular wideband digital communication schemes, whether the environment is wireless or over copper wires, used in applications such as DVB and DAB, wireless networking and IP-broadband internet access. The data is divided into several parallel data streams or channels and each sub-carrier is modulated with a conventional modulation schemes at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. In terms of mobile radio, a selective frequency fading channel is converted into a collection of parallel flat fading sub-channels and this greatly simplifies the structure of the receiver [6]. Hence, the available bandwidth is utilized very efficiently in OFDM systems without causing the Inter-Channel Interference (ICI) [2]. By combining multiple low-data-rate sub-carriers, OFDM systems can provide a composite high-data rates with a long symbol duration. That helps to eliminate the Inter-Symbol Interference (ISI), which often occurs along with signals of short symbol duration in a multi-path channel [3].

2.2 DEVELOPMENT OF MIMO

The first idea of exploring this technique goes back to the 1970's, when A. Kaye, D. George and W. Etten [12] tried to demonstrate, by computer simulations, what benefits can come from using an array of multiple antennas. Then in the mid 1980s, both J. Winters [7] and J. Salz [8] published several papers on beam-forming. The beam-forming technique, also known as Adaptive Antenna Systems and beam-steering, was introduced as having spatial selectivity using an array of multiple antennas to provide a directional signal for transmission or reception taking benefit of interference to adjust the directionality of the antenna array. When transmitting, the beam-forming technique controls both the phase and amplitude of the signals in each antenna, in order to generate a pattern of constructive and destructive interference in front of the wave. Fig. 1 illustrates how beam-forming works by distributing the communication energy in different ways in space, with the help of multiple aligned antennas. In 1984, J. Winters [7] introduced a new technique to transmitting data information by the use of multiple antennas at both ends of the communication system (Tx and Rx) over the same spectrum band (frequency and time). J. Salz [8] in 1985 investigated the joint transmitter-receiver optimization with the use of the Minimum Mean Square Error (MMSE) standard. In 1993 [9], A.J. Paulraj and T. Kailath proposed the concept of Spatial Multiplexing using MIMO, used to increase the capacity of wireless broadcast communications system from a central studio to a number of subscribers in a disclosed service region. The receiver exploits the directions-of-arrival differences of these co-channel signals to separate them into the individually transmitted signals. Thus, the broadcast information capacity can be improved several fold without increasing the allocated channel bandwidth. In 1996, G. Raleigh and J. Cioffi [10] anticipated new aspects for improving the efficiency of MIMO systems. The paper showed that with the appropriate communication structure been employed, the existence of multi-path would greatly improve the achievable data rate. An asymptotically optimal Spatio Temporal Vector Coding communication architecture (STVC) was suggested as a means for achieving MIMO channel capacity. After that, in 1998 [11], both J. Winters and J. Salz, represented a more important superior in MIMO area. The paper explained upper bounds on the bit error rate (BER) of optimum combining in mobile wireless systems using coherent detection of Binary Phase Shifting Keying (BPSK) and QAM signals, differential detection (DPSK) and multiple co-channel interferers within a Rayleigh fading atmosphere.

In the same year, 1998, Bell Labs was the first to show a laboratory prototype of spatial multiplexing technology which improved the performances of MIMO communication systems.

2.3 DEVELOPMENT OF OFDM-MIMO TECHNOLOGY

Recent research suggests that the implementation of MIMO aided OFDM in new generation mobile network systems is more competent than previous communication networks, given more benefits as mentioned before. OFDM-MIMO technology, which is claimed to be invented first by Airgo Networks [14], produced the basis of all candidate standards planned for IEEE 802.11n [13]. Lately, the OFDM-MIMO topic has gained more interest and attracted extensive research efforts. Innumerable papers have been published about this new technique addressing numerous aspects, for example date rates, system capacity, channel estimation, peak-to-average power ratio control (PAPR), frequency/time/space coding techniques, receiver architecture designs, etc. Recently, in 2004 two papers were published by a group of researchers, Paulraj et al [15] & Stuber [16] provided compelling overviews of the new technology “OFDM-MIMO” showing all the aspects and benefits that came with technique. Additionally, Nortel Networks has developed a prototype of the technology during late 2004, which established the dominance of OFDM-MIMO over today’s networks in terms of the feasible data rate [17].

3 RESEARCH PROJECT PLANNING

The main area of work in this research project will be the high Doppler spread of signals between transmitter and a fast moving receiver. The research will exploit novel coding/decoding schemes in the presence of high Doppler shift in both Tx and Rx architecture, and demonstrate a new channel estimation (CE) to calculate accurately the information which will be the main part of the mobile OFDM-MIMO receiver model. More focus will be done by modeling different architectures of mobile Rx to achieve best overall system performances. Furthermore, the novel OFDM-MIMO architecture will examine a High Altitude Platform (HAP) payload integrating with satellites in real world simulation scenarios. This will include targeting users traveling within high speed trains, cars on motorways and aircraft communications.

3.1 DOPPLER EFFECT

Every year vehicles, trains and aircrafts are gaining in speed which leads to many problems such as ISI, ICI, fading and Doppler effects. The main focus of the research will be in the effects of Doppler related to the challenges of high mobility between the OFDM-MIMO systems and users subscribing to these communication networks. The occurrence of Doppler shift makes the wireless channel fast-time variant and frequency selective. As well as affecting synchronization, channel estimation and data recovery. This destroys the orthogonality in data transmission making ICI appear again between the sub carriers. The connection between the Doppler freq. shift (f_d) and the carrier freq. (fc) is given generally in Equation (1):

$$f_d = \left(\frac{v \cdot f_c}{c}\right)\cos\theta \tag{1}$$

Where: v is the comparative velocity between the transmitter and the receiver (positive value when each are moving in different directions); c speed of light (3×10^8 m/s); θ is the angle signal transmission between the transmitter and receiver.

3.2 NOVEL ENCODING/DECODING SCHEMES

Encoding can be considered as the embedding of signal constellation points in a higher dimensional signaling space than is needed for communications. Therefore, in order to keep the bit error rate probability (PBE) as low as possible (error free communication) a proper channel and data coding technique are needed to reduce incorrect detections in the receiver side. Depending on the Signal to Noise Ratio (SNR) the Shannon theory as in Equation (2) limits the channel capacity (C) relative to the bandwidth (BW) used.

$$C = BW \log_2(1 + SNR)\ bps \tag{2}$$

In this section, some of the encoding (signaling) techniques designed for AWGN channels and fading channels are mentioned, that would help to create a novel code design scheme that can combat performance degradation due to different channel impairments in signal transmission, especially the Doppler Effect. Different modulation schemes will be considered in simulation such as BPSK, QPSK, DPSK, QAM, 16QAM, 64QAM. A space-time-frequency code (STFC) is a tactic for mapping information symbols to antennas as a means for extracting both spatial and frequency diversity. This will lead to proposing a new method for transforming the transmitted sequences in fast fading channels.

3.3 NOVEL CHANNEL ESTIMATION METHOD

The research will also aim to propose new channel state information (CSI) estimator technique, which is one of the main parts of the algorithm that copes with the change in data transmission between the transmitter and the receiver of the OFDM-MIMO communication system due to high mobility causing Doppler Shift. The reason of CE is to identify the channel between each join up of transmit and receive antennas. Also, the need of accurate CIS is requisite in OFDM-MIMO for space-time coding at the transmitter and signal detection at the receiver in a way that affects the overall performance of OFDM-MIMO systems [2, 3]. Before simulating the new channel estimation, there will be an investigation into the work that has been done so far in previous channel estimation methods that have been proposed to MIMO and OFDM systems recently, including methods such as blind channel, training-based, Least Square (LS), Minimum Mean Square Error (MMSE) [1], where calculating the accurate data symbols from highly mobile channels is still a major drawback for these techniques. Two antennas for both the transmitter and the receiver will be considered in the beginning (MTx=MRx=2) as in Fig. 2 then increasing the number of antennas in both sides while reviewing the overall system performance in terms of BER, throughput, MSE. First, the binary data b [n, k] is transformed into two different block signals (Si [n,k] : k=0,1,…, K-1), where i and k are the number of sub-channels of the system. At the receiver side, the FFT/DFT of the received signal from each Rx antenna is the superposition of the two transmitted signals, which can be expressed as in Equation (3):

$$r_i[n,k] = \sum_{i=1}^{2} H_{ij}[n,k] S_j[n,k] + w_i[n,k] \tag{3}$$

Where *Hij [n, k]* represents the channel frequency response at kth tone of the nth block, and *Wi [n, k]* is the AWGN, and the impulse response and frequency response of the mobile wireless channel is defined in Equations (4) and (5) respectively, where τk is the delay path, γk the complex gain and δ (τ) the shaping pulse.

$$h(t,\tau) = \sum_k \gamma_k(t)\,\delta\left(\tau - \tau_k\right) \tag{4}$$

$$H(t,f) \cong \int_{\infty}^{+\infty} h(t,\tau)\, e^{-j2\pi f t\tau}\, d\tau = \sum_k \gamma_k(t) e^{-j2\pi f t \tau_k} \tag{5}$$

This effort will consider on the receiver side only by building different models designs that work perfectly in data detection for high mobility subscribers. Results and simulations will be carried out showing different Doppler shifts and measured in terms of MSE, SNR, BER, channel throughput.

3.3 HYBRID OFDM-MIMO-HAPS-SAT. SYSTEM

Finally, the research will be testing the novel OFDM-MIMO transceiver as the payload of a High Altitude Platform system (HAPs) in different integration scenarios, including satellite systems following the work of the paper that was presented in 2009 [18] at the 10th Annual Conference on the Convergence of Telecommunications, Networking & Broadcasting (PGNet2009), under the title

"Performance Evaluation of a WiMAX Enabled HAPs-Satellite Hybrid System". It was shown that the performance of the HAPs networks with WiMAX payload, which functioned as Transmission Control Protocol (TCP) splitter to reduce the huge propagation delay that is caused in the uplink (UL) and downlink (DL) terminals between the user and the satellite network. Finally, experimental results and observations will be taken from different model schemes and scenarios in fixed simulation lengths. The general idea of the project is to build an OFDM-MIMO transmitter and a mobile OFDM-MIMO receiver, which includes new novel aspects as mentioned in previous sections. Also, including the OFDM-MIMO system as the HAPs payload as part of a hybrid network, including satellites, showing the best integration that serves clients demand on IP-broadband services and applications as shown in Fig. 3.

4 CONCLUSIONS

The possibility of using OFDM-MIMO technology as a robustness communication system against the high Doppler effects on users travelling within high speed vehicles (highly mobile environment), especially when accessing various IP-broadband services has been presented. In this report a comprehensive literature review has been introduced to identify a solution for the main drawback. A project plan has been discussed which will lead to the building and modelling of a new prototype transceiver, going through modifying and developing the major parts on each side of the communication network (Tx/Rx). Finally, the novel model will be tested in real virtual simulation scenarios as HAPs payload supported with satellite systems in hybrid architectures.

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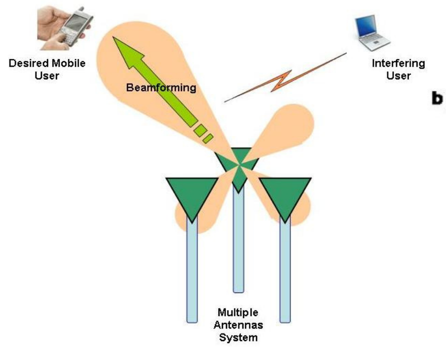

Figure 1: Diagram of the beam-forming technique

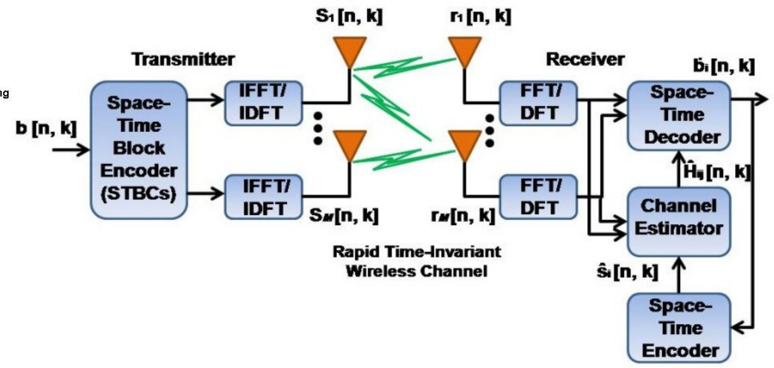

Figure 2: Schematic diagram of the MIMO-OFDM system

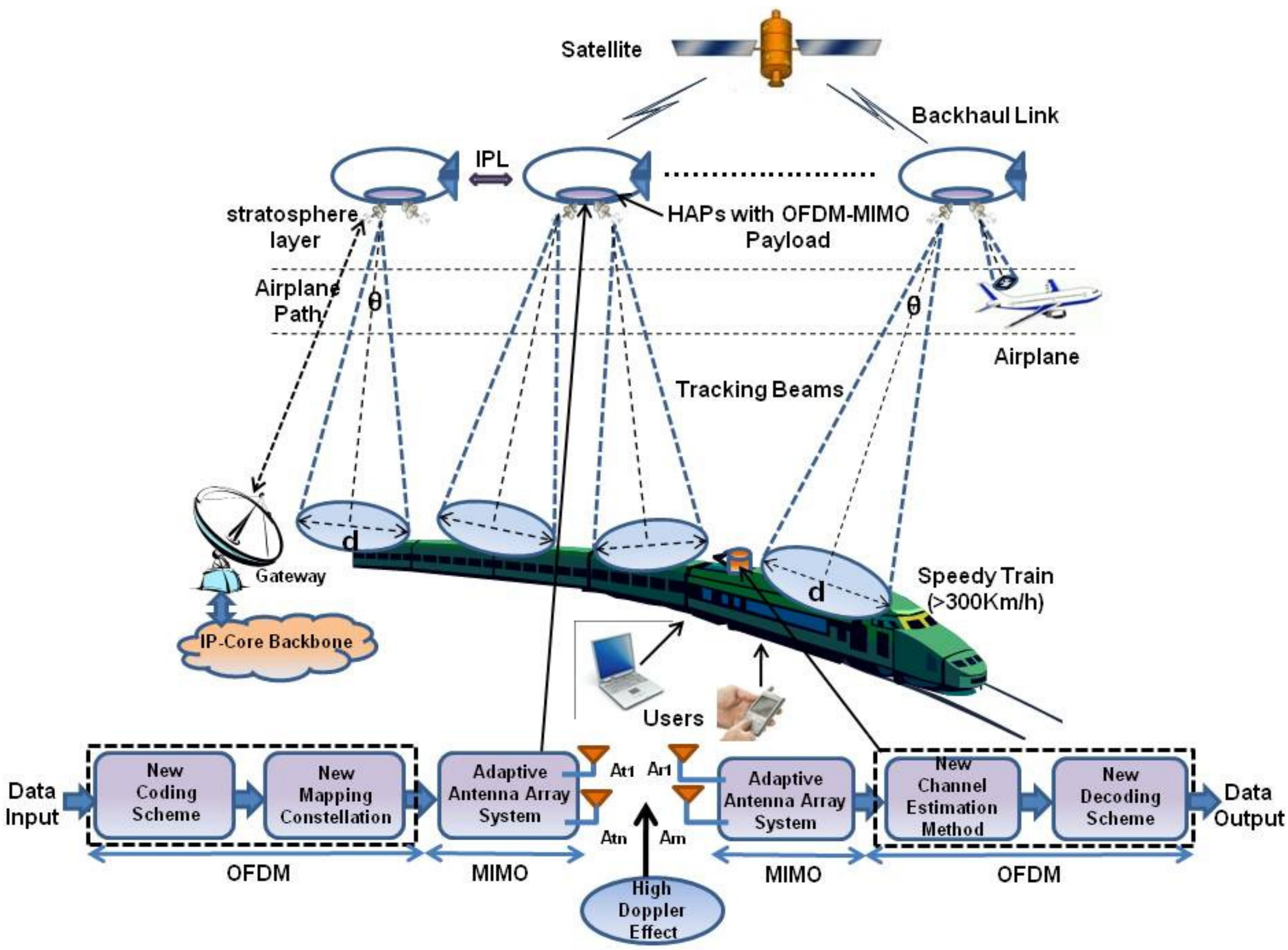

Figure 3: Hybrid OFDM-MIMO-HAPs-Satellite System