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OFDM: A potential Candidate for 5G Networks

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is the broadband multicarrier modulation method that ensures high performance and benefits over older and traditional single-carrier modulation methods which is suitable with nowadays high speed data requirements and operation in the Ultra High Frequency (UHF) and microwave spectrum. OFDM has the potential to be an effective means to capture multipath energy, mitigate the inter symbol interferences, and offer high spectral efficiency especially in broadband communication by using a large number of parallel narrow-band sub-carriers rather than a single wide-band carrier in order to transport information. OFDM is currently an emerging technique leading the researchers to apply such techniques in 5G networks. Therefore, we present an extensive and exhaustive review on OFDM. The main purpose of the paper is to enrich the knowledge based society with OFDM under one roof to facilitate the researchers to tailor their research towards 5G networks.

Keywords: OFDM, MIMO-OFDM, UHF, Broadband communication

I. INTRODUCTION

In communication systems, the increasing demand for high data rates over wired and wireless networks resulting the adoption of Orthogonal Frequency division Multiplexing (OFDM) technology which offer high rate transmission with low complexity for implementation over frequency-selective fading channels. The OFDM is a type of channel detection system for capturing multipath channel, mitigating the effect of inter-symbol interference (ISI) where each symbol is added with cyclic prefix (CP), providing high spectral efficiency, and apply fundamental concept of cooperative diversity in order to improve the performance. In multiplexing of OFDM, the receiver will be able to estimate the channel and track its fluctuations using time frequency transmission grid. Application which adopted OFDM are DAB/DVB for digital audio and video broadcasting system, high-rate WLAN such as IEEE802.11a, HIPERLAN II and terrestrial DMB for digital multimedia broadcasting system.

For cellular OFDM, cells are distinguished by cell-specific pattern in preamble for identification from the set of candidate pattern after synchronization process in receiver known as (CID) cell identification process. On the other hand, Multiple Antenna (MA) OFDM is a solution for supporting high rate communications over frequency selective fading channels which need reliable time and frequency synchronization as well as accurate channel estimation. The Space Division Multiple Access (SDMA) OFDM offers higher capacity than single antenna system which allows users to communicate within same time-slot and frequency band by differentiate it using Channel Impulse Response (CIR). It is to ensure provide diversity gain through the use of multiple transmit antennas. The Space-time block code (STBC) received a lot of attention due to simple linear decoder that can be use at the receiver side. In multiuser OFDM, the frequency offset is caused by oscillators mismatch or Doppler effects caused by user mobility that lead to inter-carrier interference (ICI) and multiuser interferences (MUI). These interferences resulted the increase of BER of the system where it occur for the uplink but does not effects the downlink case which characterised by difficulty of signal detection. This signal detection caused by lack of coordination of independent mobile users.

After OFDM, OFDMA stands for Orthogonal Frequency Division Multiple Access is introduced which is considered as an extension of OFDM to multiple users where subset of subcarriers is assigned exclusively to each user [1] and inherit the superiority of mitigating multi-path fading and maximizing the spectral efficiency. It is based on the observation of fading statistics independency where a deep fade subcarrier that are not usable for one user will not be usable for other users at the same time. The transmission bits for each user will be distributed to the sets of subcarriers to utilise the resources efficiently for example channel bandwidth and transmission power. The OFDMA apply cross layer scheduling by select a set of users with best channel condition for each subcarrier. This will increase the efficiency of spectral system for multiuser diversity gain (MuDiv) on system throughput. Each of the subcarrier received different channel and received (SINR) Signal to Interference and Noise Ratio. However, the knowledge for state of the channel at the base station (CSIT) is assumed to be perfect as the packets errors can be ignored even in slow fading channels by the careful rate adaptation as well as applying strong channel coding for transmitted packets.

The OFDMA combined with Space Division Multiple Access (OFDMA/SDMA) support high speed wireless communications since it use beam-forming technique in multiple-antenna system and multiplexes multiple users on the same sub-channel to increase system throughput [2]. Multiple Inputs Multiple Outputs (MIMO) was proposed to solve the Bit error rate (BER) and system performance over flat fading channels. The virtual MIMO array becomes a cooperative communication through relay nodes for channel capacity enhancement, throughput and enabling new architecture for better performance. The transmission of data through relay networks contains high spectral efficiency which need standardization of relay network protocols. Usually space time coding or spatial multiplexing (SM) used for exploit benefit offered by MIMO links by transmitting several data streams across the wireless MIMO channel simultaneously. Some research have been devoted in order to optimized the mutual information of a MIMO system with interference [3][4]. Signalling methods were developed for optimizing the mutual information of MIMO system where user in one cell suffers from co-channel interference from users in other cells. In blind channel estimation methods, the method can be classified into employing second order statistics (SOS) and using higher order statistics (HOS) [5]. For SOS method, a subspace method is proposed in order to estimates the channel up to an ambiguity matrix and relies on virtual subcarrier to estimate the channel although with insufficient guard interval up to an ambiguity matrix. Besides that, in SOS methods also employ pre-coding and yielding the channel estimates up to a phase rotation.

Therefore, most existing OFDM multiuser resource allocation schemes are not suitable for packet-switched wireless networks. As a result, the PHY (physical) layer may allocate subcarriers and power to a user who has very few backlogs in its queue, which causes a waste of resource. OFDM would not be able to exploit the multi-path diversity without channel coding across subcarriers as well as due to spatial multiplexing in MIMO-OFDM, the length of signal block can be shortened. In addition, it is critical to take into consideration of packet errors in the cross layer design for robust performance with imperfect CSIT. In the downlink case, each mobile station (MS) knows the frequency offset and channel response affecting its receiver only, but not those of other users. Due to the lack of coordination among receiving users, spatial layer separation is not possible at the receiver end for the usual case of transmission to several users simultaneously.

The remaining sections of this paper are organized as follows. In Section II, model of the emerging of OFDM systems is described. In Section III, the comparative analysis is discussed and presented with the table of comparison. Finally, in the last section, the future trends of OFDM are discussed and added with the conclusion.

II.RELATED WORK

Based on several papers, there are various related works involves in pursue the objective of the paper. Based on W.Nam & Y. Lee includes several system model of interest and discuss the derivation of several schemes: The optimal CID schemes based on the Bayesian approach and the maximum likelihood (ML) approach, a suboptimal scheme that is a simplified version of the ML approach, a differential decoding-based scheme and compared the complexity of the CID schemes [6]. A study by A. Feiten et. al. state a precise problem formulation and related system model as well as solution of the single user OFDM optimal rate allocation problem by help of directional derivatives [7]. Y. C. Tsai et. al. provided some basicsabout the SLM technique and a side-informationfree SLM scheme for turbo coded OFDM while Z. Mao et. al. describes model of OFDMA systems and present the problem formulation for RRA problems and discuss on the BnB-based fast optimal RRA algorithm[8].

In [9], their paper includes assuming the channel state is binary, numerically evaluates the effect of user mobility on SINR estimation error, and investigates the effect of SINR estimation error on the data rate and proposes an improved SINR estimator for downlink scheduling. In [1], several point that related to the topic which are signal of each user experiences independent channel realizations, its consequences and prove it by including related studies. [10] includes several technologies and its functions that is related to the studies such as smooth migration toward 4G, 3G LTE (Long Term Evolution) plan, and the working assumption for 3G LTE cell search. In [5], its includes related works such as cooperative communications are a set of techniques to improve wireless networks performances by generating spatial diversity, cooperative – communications at all link level have been widely studied in uplink cellular networks , and downlink relaying has only been studied for coverage improvement, using relays as repeaters without diversity.

In [11], many methods have been proposed to mitigate ICI from OFDM systems in the literature. Examples are the ICI self-cancellation or polynomial cancellation coding method is attractive for its simplicity and particularly interesting when there are multiple frequency offsets as in cooperative systems, combine ICI self-cancellation scheme with space frequency codes to achieve full diversity as well as mitigate ICI in MIMO-OFDM systems, and timing errors are concerned and the scheme is amplify-and-forward (AF) based and OFDM is implemented at the source node.

In [12], they provides an approximate closed form solution to the problem of maximum likelihood (ML) estimation of the carrier frequency offset (CFO) in an orthogonal frequency division multiplexing (OFDM) signal transmitted over a multipath fading channel. This results in a novel feedforward frequency synchronizer, requiring only an approximate statistical knowledge of the communication channel. The performance of the proposed algorithm is assessed by computer simulations and is compared with that provided by other synchronizers and with Cramer-Rao bounds.

In [13], they present and algorithm that finds an optimal solution of the energy allocation problem; however, since the computational complexity of this algorithm is high, we also present a heuristic algorithm that has much less empirical computational complexity and produces an optimal solution for all of the scenarios that we examine in this letter. We apply these algorithms to a performance comparison study of various schemes as a function of the total energy per symbol and as a function of the number of antennas used. an enhanced receiver (Rx) configuration for Multiple-Input, Multiple-Output (MIMO) OFDM systems, operating under the composite effect of PHase Noise (PHN), Residual Frequency Offset (RFO) and the transmission channel, herein modeled as quasi-static but unknown was also proposed. The proposed Rx identifies the different impairments by exploiting their different time constants and compensates for each one accordingly. It includes a novel inter-frame Fine Frequency Synchronization (FFS) scheme, which is closely coupled to an intra-frame adaptive phase synchronizer/channel estimator. The proposed scheme is evaluated for a 2×2, Alamouti Space-Time Code (STC), and is shown to provide significant performance gain. The theory can be employed with any other STC scheme.

III. Comparison Analysis

The Orthogonal Frequency Multiplexing (OFDM) is introduced as a technique against everything that counteracts the high data rate wireless transmission. Unfortunately, the combination of different signals with different phases and frequency gives large dynamic range that is used to be characterized by a high Peak to Average Power Ratio (PAR), which results in severe clipping effects and nonlinear distortion if the composite time signal is amplified by a power amplifier. The recent paper have discussed the method using power loading rely on the general understanding that if the transmitter has a-priori knowledge regarding the channel (channel state information), then it may pre-equalize the transmitted symbols to combat the adverse effects of the channel. The transmitter may, for instance, allocate more power to the sub-carrier experiencing deep fades. Compare with the method that use classical discrete Fourier transform (DFT)-based channel estimation for optimal gradient vector at the first iteration such that the error propagation effect is mitigated where occurs a new trend in mitigating the peak power problem in OFDM systems is proposed., based on modeling the effect of power amplifier nonlinearities on OFDM systems.

Another trend that can be discussed is about the concept of MIMO-OFDM systems. MIMO is considered a key technology for improving the throughput of future wireless broadband data systems MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without requiring additional bandwidth or transmit power. This is achieved by higher spectral efficiency and link reliability or diversity (reduced fading). There is a paper that discussed that OFDM cooperative protocol that improves spectral efficiency over those based on fixed relaying protocols while achieving the same performance of full diversity and practical relay-assignment scheme for implementing the proposed cooperative protocol in OFDM networks. For future trend, the new technologies has been introduced that MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wifi), IEEE 802.16e (WiMAX), 3GPP Long Term Evolution (LTE), 3GPP HSPA+, and 4G systems to come. Radio communication using MIMO systems enables increased spectral efficiency for a given total transmit power by introducing additional spatial channels which can be made available by using space-time coding.

A. *Technique and Strength*

OFDM can be introduced into different technique. The technique is based on cooperative protocol that improves spectral efficiency over those based on fixed relaying protocols while achieving the same performance of full diversity. The strength of this protocol is that the transmission of data can be uniformly distributed over fixed probability. As we know that, the cell contains one central node and multiple users, so that's mean each transmission is communicating with the central node. Another strength is the central node can be a base station or an access point in case of the WPAN, and it can be a piconet coordinator in case of the WPAN. Although it has several strength, but it has a weakness in terms of transmission where the transmission is constrained to half-duplex mode because we assume that each node is equipped with single antenna. OFDM can also make errors during modulation such as symbol error rate (SER) or average capacity and can be reduced by power loading on the sub-carriers. Power loading techniques rely on the general understanding that if the transmitter has a priori knowledge regarding the channel state information, then it may pre-equalize the transmitted symbols to combat the adverse effects of the channel. The strength of this technique is minimizing the average OFDM symbol error rate while providing PSAM and uniform pilot locations throughout the sub-carriers by estimating the channel. This technique also introduced different models such as channel model and transceiver model by approaching power loading for closed-loops system with channel information feedback. The purpose of these techniques is to estimate the channel response at time to be used for coherent detection at the receiver as well as using the estimate and relay the pilot index vector to be used for transmission. The optimization only can be done or calculated at the data locations only, so it is very limited to the signal error rate from other locations.

Another technique is by using CSIT model and frequency selective fading channel model where both techniques are applied on the downlink transmission in OFDMA systems. The channel is assumed to be time-invariant. Compared to the previous paper, the technique used for channel response at time but in cross layer OFDMA systems with perfect CSIT, the system throughput increases the scale capacity. There will always have packet error during modulation in the systems. Therefore, the techniques are not really efficient in terms of performance because of the outdated status which resulted from feedback or duplex delay. There is a research paper stated that the problem of efficient usage of subcarriers in downlink OFDMA multi-hop cellular networks. This technique involves quality of service (QoS) requirements, interference of other cells. Transmission mode selection is been proposed by determining whether multi-hop transmission is the transmission mode most appropriate for minimizing the resource used to guarantee a certain QoS. The multi-hop is gain as the amount of subcarriers saved by using two-hop transmission instead of single-hop transmission. Before this, there is a technique earlier mentioned that the closed loop is used for reducing errors in OFDM system. Closed loop techniques, such as transmitter pre-coding can overcome ill-conditioning of the channel matrix and improve the system performance. The weakness of this technique is although a combination of OFDM and closed-loop MIMO realizes large capacity gains on frequency-selective fading channels, subcarrier orthogonality, an essential feature of OFDM, is lost if there are carrier frequency offsets caused by a Doppler shift resulting in inter-carrier interference and an error floor. The performance loss increased as the carrier frequency, OFDM symbol size and vehicle velocity increase.

Another process considers the resource allocation problem in the wireless OFDMA system with a relay node. As a result of the orthogonal relay node constraint, the use of relay node may enhance or degrade the achievable transmission rate depending on the instantaneous channel states between source and relay, relay and destination as well as source and destination. The weakness of this technique is when a relay node is used to transmit the message to the destination, the source node cannot transmit on the same time or frequency slot and there is a price or overhead associated with using the relay. Optimal modulation and coding scheme selection criterion for maximizing user throughput in cellular networks with the help of link adaptation (LA) techniques significantly increase user throughput. It was providing efficient ways to maximize spectral efficiency with the instantaneous quality of wireless channel. However, the technique did not consider the performance improvement through HARQ operation. They approximated the user throughput without estimating the exact expected throughput obtained through HARQ operation in retransmission. Preamble-based cell identification schemes are derived for OFDM systems. In OFDM systems for instance IEEE 802.16e, the cells are distinguished by the cell-specific pattern in the preamble. After the synchronization process in a receiver is completed, the pattern in the received preamble signal can be identified from a set of candidate patterns. This process is called cell identification (CID). Conventional methods for CID are based on some kind of cross-correlations between the received signal and the candidate patterns. In OFDM system, there is also have multiuser channel where the present correspondence deals with the rate and power allocation problem has occurred. Finding a rate allocation to subcarriers in a multiuser OFDM system which minimizes the total power consumption under the constraints that each user receives the required minimum transmission rate. The system model consists of different types of algorithm such as a Successive User Integration Algorithm (SUSI). This algorithm is done once subcarriers are assigned to users, the optimum rate and power allocation is easily determined by applying the results is now used as a building block for a heuristic algorithm which first affiliates users into the system and then locally exchanges user subcarriers to improve power consumption. Another algorithm is for benchmarking purposes we devise a branch-and-bound algorithm which assigns subcarriers to users in an optimal way once the maximum numbers of subcarriers per user are fixed. A selective-mapping (SLM) scheme which does not require the transmission of side information and can reduce the peak to average power ratio (PAPR) in turbo coded orthogonal frequency-division multiplexing (OFDM) systems is proposed. The basic idea of SLM technique is to generate several OFDM symbols as candidates and then select the one with the lowest PAPR for actual transmission. Conventionally, the transmission of side information is needed so that the receiver can use the side information to tell which candidate is selected in the transmission. The strength of such an arrangement is that no additional protection is needed for side information and the rate loss due to the side information is small. However, once the side information is incorrectly decoded, the number of error bits in the erroneously decoded codeword can be great. In an ideal OFDMA system, the transmission bits of each user are optimally distributed among a set of subcarriers to efficiently utilize the radio resources such as channel bandwidth and transmission power. However, the exist problems for these scheme consists of two classes of radio resource allocation (RRA) problems which are the margin adaptive (MA) and the rate adaptive (RA) problems. There is an algorithm named fast optimal RRA based on branch and bound approach where in general, exhaustive full-search algorithm is a basic method for solving integer programming problems. For the RA problem, the complexity of an exhaustive full search algorithm which is exponential in the number of subcarriers and makes it not a practical solution. In this section, an efficient fast optimal algorithm based on BnB approach is proposed to reduce the complexity. Compare to previous techniques which is CSIT model, Spectral efficiency and error resilience in these applications are well known to improve with the knowledge of channel state information (CSI) at the transmitter (CSIT). For this reason, OFDM transmissions over wire line or slowly fading wireless links have traditionally relied on deterministic or perfect (P-) CSIT to adaptively load power, bits and/or subcarriers so as to either maximize rate (capacity) for a prescribed transmit-power, or, minimize power subject to instantaneous rate constraints. However, the assumptions of P-CSI at the transmitters and receiver render analysis and design tractable, they may not be as realistic due to wireless channel variations and estimation errors, feedback delay, bandwidth limitation, and jamming induced errors.

Orthogonal frequency division multiplexing based wireless systems are spectrally efficient, but they are vulnerable to inter carrier interference (ICI). In a wide area scenario, users will experience varying signal strength due to different individual path loss and also varying amount of Doppler spread because of their independent velocities. Therefore, there is one technique proposed in this work to use dynamically adaptive sub carrier bandwidth (ASB) along with adaptive bit loading to mitigate ICI in such conditions, which will keep receivers simple while maintaining maximum throughput in each situation. The strength of this technique is users with similar requirement of sub carrier bandwidth may share a time slot. The entire available bandwidth may be divided into sub–bands with different sub carrier bandwidth in each sub band. Each sub band can be operated on by an IFFT with different number of sub carriers. But in this process still need guard bands for avoiding one sub band interfere with other sub band; this will cause loaded memory and delay.

Alamouti coded orthogonal frequency-division multiplexing (OFDM) scheme for a cooperative communication system robust to both timing errors and frequency offsets. OFDM with cyclic prefix (CP) is used to combat timing errors. In order to mitigate the inter-carrier interference (ICI) caused by multiple frequency offsets in the cooperative system, an ICI-self cancellation scheme is constructed, which can suppress ICI effectively. Therefore, space-time coding is an effective technique to exploit spatial diversity through multiple antennas in a MIMO system and multiple transmissions from multiple nodes in a cooperative system where there is one algorithm introduced named ICI self-cancellation scheme combined with Alamouti code. The main idea of the symmetric data-conjugate method is to utilize the symmetric conjugate-negative property of ICI weighting function Qi. The weakness of this technique is only timing errors are concerned and the scheme is amplify-and forward (AF) based and OFDM is implemented at the source node, while in this paper, both timing errors and frequency offsets are considered and the scheme is decode-and forward (DF) based and OFDM is implemented at the relay nodes.

B. Weaknesses and Problems

OFDM has been a widely accepted technology in high rate and multimedia data service systems, such as 3G Long Term Evolution (3G LTE) system in the 3rd Generation Partnership Project (3GPP). New cell search scheme based on the frequency domain sequence hopping of synchronization channel symbols. The cell search procedure consists of two steps: In the first step, an MS finds P-SCH sequence index and P-SCH symbol timing (5 msec timing) using three time domain matched filters which correspond to the P-SCH sequences. In the second step, the MS detects S-SCH sequence index and 10 msec frame timing based on frequency domain correlation using 340 S SCH sequences. One weakness of the current 3G LTE cell search scheme is the computational burden in the first step since matched filter operation requires a large number of complex multiplications. Another weakness is that both synchronization steps experience severe performance degradation under a large frequency offset environment. As we mentioned earlier, the error mostly occur at downlink transmission but now is at the uplink transmission where a low-complexity algorithm with fairness consideration is proposed to maximize the sum rate under individual rate and transmit power constraints. Water-filling implementation algorithm for the two-user case and a low-complexity version where the latter achieves a near-optimal performance when the two channels are identical, or when the signal-to-noise ratio (SNR) is high. However, the weakness of the above algorithms optimize the system throughput without consideration of the instantaneous fairness among users and they usually have high implementation complexity.

Multi-user orthogonal frequency division multiplexing (OFDM) has attracted much attention as an effective transceiver technique for high-speed multi-user wireless systems that can provide high spectral efficiency by incorporating various advanced technologies. When proportional fair (PF) and maximum SINR (MS) scheduling schemes are employed, the data rate can be maximized by optimizing SINR thresholds for modulation level selection in consideration of the SINR estimation error, which is caused by channel feedback delay for downlink systems. When the SINR estimation error occurs because of the feedback delay and noise in the pilot signal, the achievable rate is analytically derived for PF scheduled OFDM systems with the assumption of the same average SINR for each user. However, it is required in practice to consider the situations where each user experiences different channel environments that include path loss, maximum Doppler spread, and delay spread, leading to non-homogeneous error statistics on SINR estimation. An adaptive radio resource allocation (ARRA) algorithm for downlinks OFDMA/SDMA systems integrate with multimedia traffic. This radio resource allocation work is mathematically formulated into an optimization problem with an objective to maximize the system throughput under four designed constraints. For spectrum efficiency and QoS satisfaction, the radio resource allocated to a user has an upper bound and a lower bound, which are the result of the buffer occupation constraint and the QoS fulfillment constraint, respectively. In addition, there are weaknesses on the system such as the total power and the number of users multiplexed on the same sub-channel, and these limitations are represented by the total system power constraint and the sub-channel allocation constraint.

Opportunistic scheduling algorithms, such as proportional fair scheduling and adaptive channel allocation, based on current channel states represent a promising strategy for increasing the capacity of orthogonal frequency division multiple access (OFDMA) systems. However, systems based on these algorithms work under the hypothesis that the transmitters are being provided with precise channel quality information (CQI); however, accurate CQIs, which require a large amount of feedback information, are not available on feedback channels designed to carry low-rate extra information. Channel estimation in orthogonal frequency division multiplexing (OFDM) is generally performed using pilot subcarriers. The comb-type pilot pattern is adequate for the time-varying environment and multiple-input multiple-output (MIMO) systems considering spectral efficiency, and requires an interpolation technique between pilot subcarriers. Interpolation technique in the time domain is done using DFT-based channel estimation. If the pilot spacing is identical for all pilot subcarriers, and the number of the pilot subcarriers used is greater than the maximum delay spread, DFT-based channel estimation has no interpolation error and exhibits better spectral efficiency than frequency domain interpolation.

In the multiuser OFDM system, various adaptive subcarrier-bit-and-power allocation algorithms have been investigated based on the assumption that the number of supportable users is given. Lagrangian method of optimization is used to minimize the total transmit power under the constraints of the users' QoS requirements. Although the algorithm achieves a dramatic gain in power efficiency, the high computational complexity renders it impractical. Hence, many other adaptive subcarrier-bit-and-power allocation algorithms have been proposed to reduce the complexity of allocation algorithm. However, this algorithm has its weakness even though the algorithm is designed to solve the allocation problem efficiently, this repetition causes an unacceptably high computational complexity. Such a repetition problem can happen in most allocation algorithms which assume the number of supportable users is given.

Another problem experienced by OFDM system is inter-carriers interference where it is different from the co-channel interference in MIMO systems. ICI is caused by reused channels in other sub-channels in the same data block of the same user. These problems can be solved by three techniques where the first technique is based on CFO estimation and compensation, which makes use of pilot sequences, virtual carriers or blind signal processing techniques. The second approach is based on the windowing technique in either time domain or frequency domain, such as Nyquist windowing and Hanning windowing. The third one is called ICI self-cancellation, or Polynomial cancellation coded (PCC), where the repeated bits are transmitted to mitigate inter-carrier interference. To solve the interference problems, the signal processing method together with two algorithms, namely, MUSIC-based and ESPRIT-based algorithms were been proposed. The algorithms solved the problems by compensating the CFO and once a precise CFO estimate is obtained, a perfect equalizer then can be designed to eliminate ICI. Another technique is by windowing where the multiplication operation in the frequency domain is equivalent to the circular convolution in the time domain. Different digital filtering can be affected by different by different windowing based on parameters chosen. The last approach is by intercarrier interference self-cancellation. The ICI self-cancellation scheme is a method involving with encoded redundancy. Compared with other schemes, only half or less of bandwidth is used for information transmission. In other words, only half or less of full data rate could be achieved. However, the weakness is the empirical results have shown that ICI self-cancellation outperforms the convolution coding in most channel environments.

The OFDM transmission technique has gained a lot of interest in the recent years due to its spectral efficiency and capability to overcome multi-path fading. In recent works, studies have investigated the implementation of the Inner Receiver of an OFDM-WLAN system based on IEEE 802.11a standard. Solutions for the most critical blocks, i.e. Synchronizer, Channel Estimator and Digital Timing Loop have been proposed and analyzed under careful consideration of nearly realistic transmit conditions. The proposed architecture is shown to be relatively robust against the Automatic Gain Control(AGC) effects, channel estimation noise is reduced and the residual phase error is eliminated which applicable in both LOS and NLOS channels. However, the weakness of the proposed architecture is with the performance of Digital Timing Loop (DTL). DTL is limited by the fact that only first order Farrow interpolators assure stability of the algorithm.

OFDMA is compatible with IEEE 802.16a especially in power constrained wireless mesh network (WMN) with packet scheduling and admission control, thus the packet level and the connection level performances are also investigated in the previous work [14]. The scheduling mechanism maximizes the transmission rate while the constraints on supplied power are met. A queuing analytical model has been used to investigate the packet-level performances at the mesh router with the proposed scheduling mechanism. Based on the energy-aware scheduling, router capacity in terms of maximum number of ongoing connections is obtained and a threshold-based admission control has been investigated which satisfies the connection-level QoS requirements for both relay and local connections. Thus, optimal mesh router capacity has been obtained when the amount of supplied power and the traffic loads are time-varying. In essence, with the proposed radio resource management framework both packet-level and connection-level QoS requirements can be satisfied under constrained power supply in a solar-powered wireless mesh router. However, the complexity of the WMN itself can be an issue for this model.

In achieving effective and quality-guaranteed wireless multimedia communication beyond 3G, the resource allocation methods for Multi-Carrier-CDMA systems those adopt MC/VSL multirate access and LMMSE MUD receivers is proposed. In [15], they proposed iterative algorithm jointly selects the sub-carriers and allocates the power for all users. Not limited to MC/VSL access, the algorithm is applicable to general MC-CDMA systems. The simulations also showed that when total transmitted power is minimized, the best quality sub-carrier with respect to each virtual user is selected and power concentrated, which occurs when every virtual user has one exclusively best sub-channel.

C. Related Studies and proposed solutions

A well-documented decision directed channel estimation (DDCE) methods proposed by [16] is eminently suitable for OFDM-based systems. With DDCE scheme in the absence of transmission errors, 100% of pilot information can be benefited by using the detected subcarrier symbols as a posteriori reference signal. Thus, the number of pilot symbols required can be reduced. In previous work, two DDCE schemes namely the DDCE employing the a posteriori SS-CIR estimator and its PAST-aided FS-CIR estimator based counterpart. The performance of both methods was explored in conjunction with realistic channel conditions characterized by a time-variant Rayleigh fading FS-CIR. Thus, the result shows that the latter estimation method exhibits substantial advantages in terms of the achievable system performance. However, the weakness of the method is the channel estimator for further range of cutting edge OFDM system, for example for the family of so-called direct minimum Bit Error (MBER) OFDM modems and for near-instantaneously adaptive OFDM is not provided.

In [17], the study has considered the average sum capacity of CSIT-assisted single-cell downlink multiuser MIMO-MCCDMA and MIMO-OFDMA. The systems were evaluated with and without a fairness constraint (which was modeled by constraining the maximum number of channels occupied per user). The resource allocation was modeled as a cross-layer optimization framework, and an optimal power allocation and user selection algorithm was proposed for each of the above scenarios. It was demonstrated that the OFDMA systems outperform the MC-CDMA systems due to their superiority in exploiting the multiuser selection diversity over the frequency domain. However, the study has some weaknesses which are the performance difference depends heavily on the path loss exponent and the number of antennas, as well as the fairness requirement and for delay-insensitive applications, the benefits of OFDMA overMC-CDMA are significantly reduced by the path loss or multiple antennas.

A study has investigated joint estimation of channel impulse response and frequency offset for OFDM systems [18]. A high resolution frequency-offset estimator that uses both pilot symbols and VCs has been derived. They have established the asymptotic unbiasedness and derived the asymptotic MSE and the approximate CRB. A decision-directed joint ML estimator has been derived to improve the estimates of frequency offset, data symbols and channel impulse response iteratively, and is initialized using the frequency-offset estimator and the least-squares channel estimator. Pilots and VCs design rules have also been discussed.

A closed-loop compensation algorithm with a simple scalar power offset feedback combined with interference suppression at the receiver results proposed by [19] in nearly the same performance as the ideal case where the interference structure per sub-carrier is perfectly known at the transmitter in both link and system level studies. The performance of the ideal case was found to be still better, especially at high SINR region with full eigenmode excitation. However, the algorithm has a weakness because it required signalling feedback which results to be unpractical in most applications. The results also demonstrate that in the presence of non-reciprocal inter-cell interference the quality of service at the receiver cannot be controlled if the transmission parameters are defined based on the reverse link measurements only. Therefore, some feedback to the transmitter is always needed in order to make cellular adaptive TDD MIMO-OFDM system to function properly.

MSB scheme proposed by [20] for an OFDM system under MIMO channels, where both subcarrier level and symbol level beamforming are employed. Compared with the cases where only the subcarrier based beamforming or only the symbol based beamforming are used, the MSB scheme can be employed to effectively tradeoff system performance and complexity. In the MSB scheme, three weighting matrices are required to be calculated. To achieve this task, an iterative algorithm was proposed, which achieves near optimal performance but with considerable complexity. To reduce this complexity, they proposed a reduced complexity weighting coefficients calculation algorithm, where the subcarrier level weighting coefficients are calculated following the symbol level weighting coefficients calculation. Simulation results have showed that good performance can be achieved by using this reduced complexity algorithm.

Based on [21], the study has proposed a systematic design framework to deal with the problem of limited CSIT feedback for MIMO-OFDM systems with correlated subcarriers. Based on the framework, the optimal transmission and CSI feedback strategies given the limited CSI feedback constraint is obtained. By exploiting the subcarrier correlation in the design, they obtain the optimal transmission architecture, the optimal CSI feedback strategy as well as the optimal adaptation algorithm given the limited CSI feedback constraint. Through their systematic design, they found that the feedback efficiency improves as delay spread decreases.

In [22], the study has developed an exact method for calculating the BER of a $\pi/4$-DQPSK OFDM system in the presence of frequency offset over frequency-selective fast Rayleigh fading channels. An analytical BER expression was obtained. The closed-form BER expression can be calculated directly for a small number of subcarriers. It was found that time-domain differential modulation outperforms frequency-domain differential modulation for large mean delay spread value, and is worse than the frequency-domain differential modulation for large Doppler spread.

Study conducted by [23] has formulated the cross-layer average sum capacity maximization problems for both MIMO-OFDMA and MIMO-MC-CDMA under a unifying framework by taking into consideration the channel knowledge and different fairness criteria. Optimal user selection and power allocation algorithms are derived accordingly. Multiuser diversity gains are quantified by extensive numerical results and a detailed discussion analyzing the effects of different parameters, including the path loss, number of users, number of antennas and fairness is provided.

In [24], they proposed cross MAC-PHY layer multi-server-scheduling-based resource allocation algorithms. The objective is to maximize system power efficiency while guaranteeing QoS (quality of service) and fairness. Power efficiency is crucial to the capacity of wireless networks, because high power efficiency usually leads to high spatial reuse and low error rate.

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Next, in [26], a straightforward approach is proposed to solve the ML detection over MIMO channels requires a prohibitively high complexity. OFDM would not be able to exploit the multi-path diversity without channel coding across subcarriers. Thus, the space diversity from multiple antennas can help to bring the diversity gain to OFDM systems. In addition, due to spatial multiplexing in MIMO-OFDM, the length of signal block can be shortened. This is significant to OFDM, because a signal block can experience block fading. Fortunately, the EM algorithm can solve the ML detection numerically with a low complexity through iterations. The EM algorithm can also be employed to solve the ML channel estimation for MIMO channels [3].

In [27], the focus is on the downlink scenario, which expects a higher data throughput and it is considered as the bottleneck in a MIMO system. The SM system is sensitive to the rank of its MIMO channel matrix. To prevent ill-conditioned MIMO channel matrix from affecting the system data throughput, e.g., in the downlink scenarios where the number of the transmit antennas is larger than the number of the receive antennas and the corresponding MIMO channel matrix has a non-empty null space, a transmit spatial pre-filtering scheme should be designed to feed the simultaneously-transmitted data streams into the signal space of the MIMO channel matrix, instead of wasting the transmit power in the null space of the MIMO channel matrix. Therefore, feedback of sufficiently reliable CSI from the receiver to the transmitter is crucial, especially in the downlink scenarios.

With properly designed cross-layer scheduler spatial multiplexing still offers significant system goodput gains at moderate CSIT errors. To obtain closed form solution for power and rate allocation, we established the asymptotic Gaussian convergence for the packet error (outage) probability. Furthermore, the optimal user selection is in general of exponential complexity with number of subcarrier and we show that under mild conditions, the optimal search can be decoupled from the number of subcarriers.

It is proposed by [28] to construct a set of modified maximum-length shift register sequences (*m*-sequences) to replace the Hadamard sequences for serving as the new training sequences in the ICI matrix estimation. The new modified *m*-sequences require less pilot symbol overhead than the Hadamard sequences and therefore result in a larger throughput. In addition, we design a new distributive pilot allocation scheme to overcome the difficulty of estimating non-circulant ICI matrices, which is encountered in previous study.

In [29] the proposed blind MIMO OFDM receiver operates on a frame of Ns received OFDM symbols and ICA is applied in every subcarrier, followed by reordering to overcome the permutation and scaling indeterminacy and subsequent decoding. We incorporate ICA with an iterative layered space-time equalization (LSTE) structure, which is referred to as blind LSTE. Nonlinear detection such as LSTE [30]–[32] has been shown to obtain superior performance in MIMO systems than traditional linear methods such as zero forcing (ZF) or minimum mean squared error (MMSE In our proposed reduced complexity structures, the ICA only method in Section III or the blind LSTE method in Section IV is first performed for a small number of n selected subcarriers (the reference subcarrier kr should be included in the n subcarriers for decoding). Using the channel estimates of the n subcarriers, channel estimation for the remaining (N−n) subcarriers is obtained by interpolation.

The proposed simple and bandwidth efficient closed-loop method by [33] is for compensating the non-reciprocity between uplink and downlink interference structure recent work. The basic idea of the proposed method is to apply a power offsets value at the transmitter which compensates for the frequency, time and space selectivity between TDD DL and UL. The results demonstrated that some feedback to the transmitter is always needed in order to maintain the desired quality of service at the receiver in the presence of non-reciprocal inter-cell interference. The idea has been further improved by exploiting the spatial correlation properties of the nonreciprocal interference at the receiver. They introduce a simple and bandwidth efficient closed-loop scalar power offset feedback method for compensating the non-reciprocity between uplink and downlink interference structure [31]. The proposed algorithm can be also equally used to compensate for the impact of channel estimation errors jointly with the non-reciprocal interference.

In [34] in order to utilize the diversities in frequency and space, different forms of space-frequency coded OFDM, such as space-frequency block coded OFDM (SFBC-OFDM) have also been proposed and evaluated, in terms of performance, using numerical analysis of the systems under consideration. On the other hand, closed-form expressions for the bit error rate (BER) serve as an attractive alternative to the commonly used bounds for evaluating the performance of such systems. In that paper, the closed-form expressions is derived for general SFBC-OFDM systems over frequency-selective fading MIMO channels, including exact expressions and approximated formulae for the BER. Another technique for reducing the feedback requirement becomes highly desirable. To reduce the feedback, a feasible approach is to exploit the time or frequency domain correlations among the different subcarriers. To exploit the time and frequency domain correlations, we have developed three classes of beamforming algorithms based on our recent successive beamforming (SBF) technique. The main difference between these three algorithms is that they exploit the channel correlation in different ways. Using a first order autoregressive (AR1) time-varying model and an exponential power delay profile, we calculate the inter-frame and inter-subcarrier correlations among the different subcarriers. The strength of this technique is the beamforming scheme is carried out on each subcarrier independently but, the weakness on this technique is feedback bits are required at each frame where such high feedback requirement is not feasible in a practical implementation.

In SAGE algorithm, the technique has been developed where multiple asynchronous users are present in the interleaved OFDMA uplink system. Then, the synchronization scheme should be operated in the presence of MAI induced by the other asynchronous users. In order to overcome the MAI, iterative method to estimate the timing and frequency offsets of each asynchronous user via the space alternating generalized expectation maximization (SAGE) algorithm has been proposed and employed. The SAGE algorithm has been usually employed in the study of the direction of arrival (DOA) estimation [35], multiuser detection and channel estimation and multiuser acquisition for code division multiple access (CDMA) systems. however, the timing synchronization is not required. Moreover, it deals with the time-domain received signal, which is the superposition of all active users' signals. Therefore, In order to initiate the iteration in the other users' signals are assumed as noise to make use of the frequency offset estimator proposed for single user system or the initial estimate of frequency offset is set to be zero. Then, the weakness is the rough initial estimate brings a large number of iterations, which results in the significant increase of computational complexity.

Orthogonal frequency division multiple access (OFDMA) is chosen as a transmission technique for mobile wireless metropolitan area network (WMAN). In OFDMA, subcarriers are grouped into sets, each of which is assigned to a different user. Interleaved, random, or clustered assignment schemes can be used for this purpose. In the uplink of an OFDMA system, all of the users transmitting in the same symbol should be time and frequency aligned with other users in order to prevent inter-symbol interference (ISI), ICI, and MAI. The focus of this letter is frequency synchronization and perfect timing alignment is assumed. Frequency mismatches among the uplink users as well as between the uplink users and the base station (BS) cause power leakage among subcarriers. In this cases, there are two main approaches has been introduced, namely, *feedback* and *compensation* methods, can be used to mitigate the frequency offset in the uplink of OFDMA systems. In the former, the estimated frequency offset values are fed back to the subscriber stations (SSs) on a control channel so that they can adjust their transmission parameter. However, the obvious disadvantage of this approach is the bandwidth loss due to the need for control channel. In the compensation method, the receiver compensates for the frequency offsets of all users by employing signal processing techniques. Two compensation methods are given. The effect of frequency offset is represented as a matrix multiplication of transmitted frequency domain signal with the interference matrix1. In order to reconstruct the transmitted signal, least squares (LS) and minimum meansquare error (MMSE) algorithms are applied. The LS method requires only the frequency offset knowledge of users while the MMSE algorithm requires the knowledge of signal and noise powers as well. Moreover, both methods require inversion of the large interference matrix which is computationally demanding as the dimensions of this matrix is equal to the number of subcarriers. Cancellation based compensation methods are also used for mitigating the interference due frequency mismatches. The effect of frequency offset can be modeled as a circular convolution in the frequency domain. Using this property, frequency offset is canceled by circularly deconvolving the discrete Fourier transform (DFT) output with the DFT of frequency offset vector.

Another technique is based on compensation algorithm where the assuming of that the carrier frequency offsets is investigated of effect of the imperfect. Estimation of carrier frequency offset can be achieved by using the properties of the received signal, by transmitting known pilots, or blindly of uplink users are known, or estimated, by the receiver The fact that different subcarriers are assigned to different users in OFDMA systems makes the signal separability possible since the subcarriers coming from different users will have independent attenuations. As different users are assigned to neighboring subcarriers, where most of the interference comes from, and their power levels are separable, SIC can be used to remove the interference due to frequency offset. On the other hand, in clustered OFDMA systems, the subcarriers within a cluster will observe similar fading and hence their power levels will be similar. Therefore, successive cancellation will not be efficient for these subcarriers as signal reparability is not possible. In order to overcome this problem, we apply decorrelator receiver over subcarriers within each clusters. As the size of each cluster is small (compared to the whole subcarrier range), the decorrelator receiver is possible with manageable complexity. The combination of the decorrelator and successive cancellation is proposed as an efficient method for mitigating the frequency offset in uplink OFDMA systems.

Space Time-coded has been proposed as an efficient method to combat the sensitivity of OFDM to deep spectral fades. One of the most popular STCs is the Alamouti scheme. In it is shown that the performance of this type of ST-OFDM schemes degrades drastically in the joint presence of PHN, RFO and channel-estimation errors, the latter also being affected adversely by the a fore mentioned composite phase impairments. Before this, earlier mentioned stated that the time has a problems in OFDM, here are stated that the frequency also have problems where the SFBC-OFDM solution of utilizes the simplifying assumption that the channel frequency response (CFR) remains invariant at least over δ adjacent subcarriers. This assumption, however, is not easily met in most frequency-selective fading channels with high delay spreads. As a result, the use of the conventional linear processing decoder renders poor performance due to inter-carrier interference caused by CFR variations over adjacent sub-carriers. To alleviate this problem, one possible solution is to minimize adjacent sub-channel CFR variations by increasing the number of sub-carriers per OFDM block. However, the weakness of this solution narrows down the bandwidth of each sub-channel which in turn makes the resulting SFBC-OFDM scheme more sensitive to impairments such as frequency offset and phase noise. An alternative solution is to perform space-frequency interference cancellation to minimize the errors caused by adjacent sub-carrier CFR variations. Accordingly, this paper proposes a computationally efficient successive interference cancellation (SIC) receiver that utilizes a square-root and division free recursive QR (SDRQR) decomposition algorithm based on scaled Givens rotations. The avoidance of square-roots and divisions has significant benefits with regards to simplified receiver implementation since these operations are computationally intensive due to their high bit precision requirements. Furthermore, we analyze the performance of SDRQRSIC taking into account the effects of channel estimation errors and error propagation during SIC. Lastly, we provide performance and complexity comparisons, between SDRQRSIC and previously proposed receivers for SFBC-OFDM, to emphasize the benefits of SDRQR-SIC's suitability for receiver implementation.

Table 1.0: Table of Comparison

Techniques	Strength	Weakness
Closed-loop	Overcome ill-conditioning of the channel matrix Improve the system performance	Although a combination of OFDM and closed-loop MIMO realizes large capacity gains on frequency-selective fading channels, the subcarrier orthogonality which is an essential feature of OFDM, is lost if there are carrier frequency offsets caused by a Doppler shift resulting in inter-carrier interference and an error floor
Link adaptation (LA)	Increase user throughput that was providing efficient ways to maximize spectral efficiency with the instantaneous quality of wireless channel.	The technique did not consider the performance improvement through HARQ operation. They approximated the user throughput without estimating the exact expected throughput obtained through HARQ operation in retransmission.
Intercarrier Interference Self-cancellation	A method involving with encoded redundancy. Compared with other schemes, only half or less of bandwidth is used for information transmission. In other words, only half or less of full data rate could be achieved. Same bandwidth efficiency will be achieved for ICI self-cancellation.	However, empirical results have shown that ICI self-cancellation outperforms the convolution coding in most channel environments
Decision directed channel estimation (DDCE)	The number of pilot symbols required can be reduced. Thus, the result shows that the latter estimation method exhibits substantial advantages in terms of the achievable system performance	The channel estimator for further range of cutting edge OFDM system, for example for the family of so-called direct minimum Bit Error (MBER) OFDM modems and for near-instantaneously adaptive OFDM is not provided.

IV. CONCLUSION

For future trend, the new technologies has been introduced that MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wifi), IEEE 802.16e (WiMAX), 3GPP Long Term Evolution (LTE), 3GPP HSPA+, and 4G systems to come. Radio communication using MIMO systems enables increased spectral efficiency for a given total transmit power by introducing additional spatial channels which can be made available by using space-time coding.

With the arise of next generation (4G) broadband wireless communications, the combination of multiple-input multiple-output (MIMO) wireless technology with orthogonal frequency division multiplexing (OFDM) has been recognized as one of the most promising techniques to support high data rate and high performance. Coding over the space, time, and frequency domains provided by MIMO-OFDM will enable a more reliable and robust transmission over the harsh wireless environment. The air-link architecture of MIMO-OFDM has also been suggested for the future 4G wireless systems. MIMO-OFDM systems provide many freedoms in space, time, and frequency. Hence, ST coding, space-frequency (SF) coding, and space-time-frequency (STF) coding can be applied in order to exploit the maximum diversity from MIMO channels.

One of the main areas where the increase in data is required is within the downlink. For this the MIMO capability is applied to the HSDPA elements of the signal. The scheme used for HSDPA-MIMO is sometimes referred to as dual stream transmit adaptive arrays - there may be up to two streams of data. HSDPA MIMO is a multi-code word scheme that uses rank adaptation and pre-coding.

The two streams of data within HSDPA-MIMO are subject to the same physical layer processing, spreading, etc. The same channelization codes can used to save on channelization code resources.

After this has been completed, linear pre-coding is applied to the signal before the resulting signals are applied to the two antennas. This attempts to make the two signals nearly orthogonal to each other. This reduces the level of interference between the two signals and also reduces the level of receiver processing required.

In order to support dual stream transmission format of HSDPA-MIMO, the HS-DSCH is modified to support up to two transport blocks per TTI - one transport block per stream.

To achieve high radio spectral efficiency and enable efficient scheduling in time and frequency domain, a multicarrier approach for multiple accesses was chosen by 3GPP. For the downlink, OFDMA (Orthogonal Frequency Division Multiple Access) was selected and for the uplink SC-FDMA (Single Carrier - Frequency Division Multiple Access).

Since radio resources are limited and data rate requirement keep increasing, spectral efficiency is unavoidable requirement in present and future wireless communication systems. Thus, OFDM has much promise in the future especially at the low cost, high capacity performance, excellent throughput and provide reliability. According to previous research works, different type of algorithm have been presented for example such as for time and frequency synchronization and channel estimation. The proposed preamble had been shown efficient in terms of performance and overhead. Besides, in OFDM, bandwidth-efficiency is also part of issues which require a cooperative protocol. Thus, relay-assignment scheme is proposed to achieve significant power saving or coverage extension. In terms of solving timing errors and frequency offsets, OFDM was used to combat the errors and integrated with ICI self-cancellation scheme to mitigate the ICI caused by different frequency offsets in cooperative system. The increased throughput with possibility of low complexity receivers makes the proposed adaptive subcarrier bandwidth (ASB) a potential candidate for consideration in future systems. It is also results in pave the path for further investigation with realistic impairment. With the advantages of OFDM such as high spectral efficiency due to nearly rectangular frequency spectrum for high numbers of sub-carriers, simple digital realization by using FTT operation, low complex receivers due to the avoidance of ISI and ICI with sufficiently long guard interval, flexible spectrum adaptation can be realized and different modulation schemes can be used on individual sub-carriers which are adapted to the transmission conditions on each sub-carrier, OFDM 's increased popularity nowadays is the desire for faster wireless technologies and the increase in multimedia application which require higher speeds.

In addition, OFDM also allows precise control of all those multiple simultaneous frequencies (carriers) used to simultaneously carry many data bits in parallel on different frequencies. With the use of the FFT on both transmitter and receiver, an OFDM system, naturally and efficiently spaces the frequencies such that they are as close together as is possible and yet are orthogonal, so maximum bandwidth with no interference between sub channels can be achieved. Some future technologies also incorporated OFDM such as 4G systems, 3GP Long Term Evolution and 3GPP HSPA+. OFDM is opted because it can supports high data rates and provide high performance.

V. References

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