Abstract

Wireless communication systems based on multi-antenna multi-carrier modulation techniques such as multi-input-multi-output (MIMO) orthogonal frequency division multiplexing (OFDM) have become the state-of-art method for a broadband data transfer. However, it is still not enough as a standalone to satisfy the ever increasing demand for high data rate transmission. To fulfill this demand, new features such as carrier aggregation (CA) and advanced multi-antenna techniques have been proposed by 3rd Generation Partnership Project (3GPP) in Long Term Evolution-Advanced (LTE-A). On exploiting the advantages of OFDM with CA and advanced multi-antenna techniques, the efficiency of the cellular networks can be significantly improved. However, OFDM signal suffers from high peak-to-average-power ratio (PAPR) problem, and high power amplifiers (HPAs) induce nonlinear distortions to such a high PAPR signal. Furthermore, another hardware impairment, i.e., phase noise caused by non-ideal oscillators significantly degrades the efficiency and performance of the system. These impairments severely limit the gains provided by the OFDM-based systems as compared to the linear systems. Hence, it is imperative to take into account the impact of nonlinear HPA and non-ideal oscillator while evaluating the performance of the OFDM-based systems. As a consequence, this dissertation is mainly focused on analyzing the performance of OFDM based CA and multi-user (MU) MIMO systems in the presence of hardware impairments.

The first part of this dissertation analyzes the impact of nonlinear HPA on multi-band CA-MIMO-OFDM system. The nonlinear behavior of the HPA is modeled by a multi-band generalized memory polynomial (MB-GMP) model. It is shown that the received symbol after down-conversion can be canonically decomposed into complex attenuation factor and additive nonlinear noise. The generalized mathematical expressions of complex attenuation factor and variance of nonlinear noise for any number of aggregated bands with any nonlinearity order and any memory depth of HPA are derived. From the derived expressions, an analytical methodology is proposed to obtain the received signal-to-distortion-plus-noise ratio (SDNR), symbol error rate (SER) and error vector magnitude (EVM) of the nonlinear multi-band CA-
MIMO-OFDM system. The proposed work also provides valuable insights on the impact of number of aggregated carriers on the error performance of a nonlinear CA-MIMO-OFDM system.

In the second part, the performance of CA dual-band (DB) MU-MIMO-OFDM system in the presence of nonlinear HPA is investigated. The HPA nonlinearity is modeled by a two-dimensional GMP model. A transmit preprocessing technique is employed to mitigate the effects of inter-user interference. The generalized expression for a signal-to-interference-plus-noise ratio (SINR) for nonlinear DB MU-MIMO-OFDM system is derived and further utilized to obtain an analytical framework to evaluate the performance of the aforementioned system in terms of SER and average capacity. Furthermore, it is shown that the nonlinear interference is a function of inter-modulation and cross-modulation products from every user and increases as the number of users increases, thus significantly deteriorating the performance of the DB MU-MIMO-OFDM system.

A theoretical framework to study the joint impact of non-ideal oscillators and nonlinear HPAs on the downlink MU-MIMO-OFDM system is proposed in the next part of this dissertation. It is shown that the received data symbol affected by phase noise and HPA nonlinearity can be canonically decomposed into following: 1) the desired signal multiplied by an attenuation factor and common phase error (CPE), 2) inter-channel interference (ICI), and 3) additive nonlinear distortion noise which is uncorrelated with the desired signal. The mathematical expression of an instantaneous signal-to-distortion-plus-interference-plus-noise ratio (SDINR) for MU-MIMO-OFDM system impaired with phase noise and nonlinear HPA is derived and then used to obtain the closed-form expression for both SER and overall capacity.

In the end, this dissertation presents an end-to-end analytical framework to evaluate the performance of the cascaded digital predistorter (DPD) and HPA structure on the MIMO-OFDM system. A joint nonlinear polynomial (JNP) model is proposed to represent the characteristics of the cascaded DPD+HPA architecture. It is shown that the received symbol after the MIMO-OFDM demodulation consists of residual noise and a multiplicative factor. By modeling the residual noise as a complex Gaussian process, an analytical methodology is adopted to obtain the received SDNR of a MIMO-OFDM system in the presence of both DPD and HPA. Further by utilizing the expression of SDNR, a closed-form expression of SER is also derived for a multi-path Rayleigh fading channel. It is shown that the SER of the MIMO-OFDM system in the presence of cascaded DPD+HPA architecture significantly improves and approaches to a linear MIMO-OFDM system.

The proposed frameworks in this dissertation can easily be utilized in various wireless standards and will be useful for a communication engineer to design a link budget for MIMO-OFDM based wireless systems without performing extensive simulations or tedious experiments.