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Original scientific paper

Enhanced Signal Quality and Spectrum Efficiency in MIMO Cognitive Radio Networks using Adaptive Non-linear Pre-Distortion Power Amplifier Linearization

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Abstract: Cognitive Radio Networks (CRNs) aim to optimize the limited frequency spectrum by enabling sharing among networks and utilizing unoccupied frequency bands. The combination of massive multiple-input multiple-output (mMIMO) and CRNs has the potential to improve the efficiency of upcoming wireless communication networks greatly. Modern communication networks require improved signal quality and spectrum efficiency. Measurement noise and crosstalk significantly impact data rates and Power Amplifiers (PAs) performance in MIMO systems. This paper introduces Adaptive Non-linear Pre-Distortion Power Amplifier Linearization (ANP-DPAL), a technique that uses a parameterized non-linear model to leverage PAs' inherent non-linearities. The adaptive pre-distortion module compensates for non-linear effects by making real-time adjustments to the input signals. ANP-DPAL employs adaptive filtering algorithms (AFA) to measure and correct for interference between channels to address crosstalk. The technique integrates accurate measurement noise estimation to enhance the linearization process further. ANP-DPAL's use of fuzzy controllers to adaptively alter pre-distortion parameters ensures system flexibility, improving signal quality in diverse communication contexts, including 5G, wireless local area networks, and satellite communications. Simulation studies demonstrate ANP-DPAL's effectiveness across various parameters, including signal linearity, Bit Error Rate (BER), and Error Vector Magnitude (EVM). Results show that ANP-DPAL significantly improves linearization, crosstalk reduction, and noise robustness, confirming its suitability for real-world MIMO communication networks.

Keywords: adaptive non-linear pre-distortion (ANP-DPAL); cognitive radio networks (CRNs); crosstalk reduction; massive MIMO (mMIMO); power amplifier linearization

1 INTRODUCTION

Cognitive Radio (CR) has emerged as a promising solution to efficiently utilize the limited radio spectrum resources, particularly in the face of the rapid proliferation of wireless applications and devices. Initially rooted in the Software Defined Radio (SDR) concept, CR was conceived to expand the available spectrum. Regulatory bodies like the Federal Communications Commission (FCC) are tasked with overseeing spectrum administration due to the growing demand driven by emerging wireless technologies. To maximize the overall performance of MIMO architectures, power amplifier linearization is essential even when measurement noise and crosstalk are present [1]. The reliability of communications can be compromised due to the degradation of signal quality caused by distortions transmitted via crosstalk [2]. Due to measurement noise, powerful linearization algorithms are required for accurate signal characterization [3]. The overall spectrum performance and statistical fees of MIMO structures are enhanced by improving the linearity of the strength amplifier [4].

Linearization guarantees the performance and robustness of wireless verbal exchange by reducing crosstalk effects and compensating for measurement noise. This allows MIMO structures to reach their full potential in providing exceptional, high-throughput, and reliable connectivity in various challenging environments [5]. The linearization of power amplifiers in MIMO (Multiple Input Multiple Output) architectures is a full-scale problem when crosstalk and size noise are present [6]. The term crosstalk describes the unwanted interference between different signal pathways in a device; in the case of power amplifiers, this interference could lead to signal degradation and distortion [7]. When multiple antennas are used in a single structure, the likelihood of crosstalk increases, particularly in MIMO systems [8]. In addition, magnitude noise makes the assignment much more complicated, as it should describe and adjust for amplifier non-linearities [9]. This assignment aims to provide better signal processing algorithms and techniques that account for dimension noise and reduce crosstalk effects [10]. Developing robust linearization methods that can adjust to the complicated and ever-changing MIMO environments is an impossible challenge for researchers [11]. To guarantee reliable and environmentally friendly communication in MIMO systems, these solutions must balance obtaining linear amplification and limiting the influence of measurement noise and crosstalk [12]. It is critical to address those difficulties to improve the performance and dependability of wireless communication structures in real-world global contexts [13].

Fuzzy logic controllers and concepts connect mathematically exact models with uncertain and imprecise real-world systems. More human-like decision-making is made possible by fuzzy logic, which permits the representation of nebulous and ambiguous information. When dealing with complicated, non-linear, or poorly understood dynamics, controllers based on fuzzy logic, like fuzzy PID controllers or fuzzy inference systems, perform exceptionally well. They show resilience in the face of disruptions and dynamic adaptation to changing circumstances. Their significance is felt in many fields, such as consumer electronics, robotics, industrial automation, and automobile systems. Fuzzy logic controllers and principles allow engineers to build smart systems that deal with imprecision, partial data, and uncertainty; this improves the systems' adaptability, reliability, and performance in many different contexts.

When multiple-input multiple-output (MIMO) systems encounter size noise and crosstalk, there are several ways to linearize the energy amplifier [14]. One such method is digital pre-distortion (DPD), which allows one to compensate for distortions in an input signal by pre-distorting it using a model of the non-linear behaviour of the energy amplifier [15]. To consider versions when running, adaptive algorithms within DPD adjust the model parameters [16]. In multiple-input multiple-output (MIMO) systems, precoding techniques control the transmitted signals and reduce crosstalk, making the receiver more sensitive to the spatial separation of signals. In dynamic MIMO settings, where crosstalk patterns may switch quickly, these methods have difficulty correctly simulating and accounting for the complicated non-linear behaviour of strength amplifiers.

Better signal processing and filtering methods are needed to handle measurement noise and crosstalk in MIMO systems. To reduce the impact of crosstalk, blind sign separation techniques, such as principal component analysis (PCA) and impartial thing evaluation (ICA), aim to separate individual indicators from the combined signals. However, these strategies may fail when there's a lot of background noise or when there's not a lot of information available about the communication environment. In MIMO structures, the ongoing difficulties include achieving powerful electrical amplifier linearization in the presence of crosstalk and dimension noise while maintaining computing efficiency, actual-time version, and correct modelling.

The increasing demand for wireless services poses significant challenges to modern communication networks, which currently struggle to achieve spectrum efficiency while keeping signal quality high. More effective usage approaches are needed due to the shortage of accessible spectrum. Cognitive Radio Networks (CRNs) may help with dynamic spectrum access and use underutilized frequencies.

Motivation of the Study

Cognitive radio networks (CRNs) are being integrated with huge multiple input and multiple output (MIMO) systems to improve signal quality, boost capacity, and improve spectrum usage. CRNs allow exploiting underused frequencies more efficiently via dynamic spectrum access, while massive MIMO's beamforming and spatial multiplexing features greatly increase network performance while reducing interference.

2 RELATED WORKS

Considering the difficulties presented by problems like crosstalk, transceiver noise, and PA non-linearity, enhancing the performance of power amplifiers (PAs) becomes extremely important in wireless communication systems. Waveform analysis and hardware-based solutions constitute two of the many approaches that have been suggested as potential answers to these problems.

Together, the three issues that [17] mention, crosstalk, transceiver noise, and power amplifier (PA) non-linearity, are tackled by the suggested solution, which uses wavelet multiscale principal component analysis (PCA). The numerical stability and bit-resolution are better than traditional DPD models in simulation and measurement. In a ZX60-V63+ PA employing LTE-OFDM signals, there are considerable benefits, as shown by the analysis of platforms based on field-programmable gate arrays and direct conversion transceivers: around 23 dB in normalized mean square error and 22 dB in neighbouring channel error power ratio.

With non-linear power amplifier distortion in mind [18], a methodology for analyzing hardware-induced crosstalk effects (H-ICE) on multiple-input multiple-output (MIMO) transmitters. The tractable results demonstrate a 3 dB drop in performance from a 2 × 2 to a 1D array and an additional 3 dB drop when moving to a 2D structure, both caused by crosstalk. The study aims to improve energy efficiency by studying the optimal back-off of transmitter input power while considering MIMO crosstalk effects.

A broadband dual-channel power amplifier (D-CPA) for multiple-input multiple-output (MIMO) communications with crosstalk reduction is presented [19]. The PA prototype can achieve low inter-channel crosstalk, high power-added efficiency, and high output power by utilizing circuit approaches such as back-via lines and second-harmonic trapping. Using a 100 MHz 256 QAM signal demonstrates the effect of crosstalk on signal quality by achieving substantial linearity without digital predistortion.

Examining the effects of backward crosstalk in 2 × 2 transmitters in conjunction with third-order power amplifier non-linearities [20] tackles this problem. To reduce distortion, it develops closed-form power back-off using Bussgang decomposition. While optimizing achievable spectral efficiency (ASE), hardware factors are considered, and sub-optimal precoders perform very near to ideal. The method's potential use with transmitters with different antenna branches is also covered.

Considering the many approaches to Over-the-air (OTA) [21] linearization for transmitter antenna arrays in 5G scenarios, tackle the challenging task of meeting the demanding standards for power amplifier (PA) linearization. Assisting radio-frequency engineers in implementing over-the-air digital pre-distortion (DPD) techniques for multiple-input multiple-output (MIMO) systems, it seeks to determine the best way for individual applications by analyzing validated methodologies.

An integrated ALFC and AVR system utilizing a Fuzzy two-degree-of-freedom tilt-integral-derivative controller (F2DOFTID) is proposed [22] for a three-area power grid that hosts different types of plants. It outperforms competing controllers because it optimizes controller parameters using the HHO algorithm. System dynamics is improved by integrating HVDC tie-lines and energy storage, confirmed by real-time analysis using OPAL-RT OP 4510 RT Lab's hardware.

Raviteja Allu et al. [23] suggested the Robust Beamformer Design in Active RIs-assisted multi-user MIMO CRNs. The author applies a norm-bounded error model to examine the effects of CSI imperfection at the secondary transmitter. With the constraints of available transmission power at the secondary transmitter, maximum allowed interference power towards the primary receiver, and the permissible amplification range at each RIS element, a problem is formulated to minimize the sum mean squared error (MSE). This problem involves optimizing the transmit beamforming matrix (BFM) at the secondary transmitter, the linear reception filters (LRF) at the secondary receivers, and the reflection coefficient matrix (RCM) at the RIS.

Zunira Abbasi et al. [24] proposed the CRN-based hybrid wideband transceiver for millimeter-wave (mm-wave) decode-and-forward (DF) relay-assisted multi-user (MU) MIMO systems. The original complex issue is framed as two sub-problems of maximizing the sum rate of a single hop to generate the frequency-flat analogue processing component in the RF domain and the frequency-dependent baseband processing matrix in the baseband domain. Using RF precoding and combining maximizes the total spectrum efficiency by taking advantage of this breakdown. In contrast, baseband processing matrices lessen the effect of inter-user interference (IUI) and interference between transmitted data streams. Lastly, model parameters are tweaked in a computer program considering ideal and imperfect channel state information (CSI).

Hafiz Muhammad Tahir Mustafa et al. [25] recommended CRN-based hybrid wideband precoding for maximizing spectral efficiency in millimeter-wave relay-assisted MU MIMO systems. To address this issue, the decode-and-forward (DF) relay node is considered in two fully linked and mixed hybrid beamforming designs. One strategy is to break the original optimization issue into smaller, more manageable pieces. Then, using a decoupled design technique, we tackle each sub-problem individually. The goal of developing the phase-only beamforming system was to optimize the total spectral efficiency, and the design of the digital baseband processing components was to restrict interference to a certain level. This study ran computer simulations by varying the system parameters in response to varying degrees of channel state information (CSI) accuracy, and it was discovered that the suggested method works.

Adaptive non-linear pre-distortion (ANP-DPAL) represents the best PA linearization method in the OTA linearization techniques review. It provides a comprehensive and tailored approach for various MIMO system applications in 5G scenarios, making it the preferred method. For best linearization performance in different operating settings, ANP-DPAL constantly adjusts to the power amplifier's (PA) non-linear properties in real time. The static, pre-determined models used by many older pre-distortion methods may not capture how the PA's behaviour evolves. When dealing with non-linearities of a higher degree, ANP-DPAL is superior. Suboptimal linearization may result from conventional pre-distortion approaches' inability to predict and account for these intricate non-linear phenomena properly. The ANP-DPAL algorithm outperforms conventional techniques in terms of linearity and distortion reduction by continually adjusting to the non-linear properties of the PA.

3 THE PROPOSED MODEL

One of the most pressing problems in trendy communique networks, particularly in multiple-enter more than one-output (MIMO) structures, is adaptive non-linear pre-distortions for energy amplifier linearization, or ANP-DPAL. By adopting a parameterized non-linear model, ANP-DPAL benefits from the inherent non-linearities of the power amplifiers (PAs) to enhance the sign's excellent spectrum efficiency. This adaptive pre-distortion approach makes real-time modifications to input signals to account for non-linear consequences caused by PA. The approach consists of accurate measurement noise estimation methods to reduce the impact of noise and uses adaptive filtering strategies to lessen the effect of channel-to-channel interference using a fuzzy controller.

The problem of crosstalk is a primary impediment to transmission in the field of multiple input and multiple output (MIMO) transmitters. Linear and non-linear crosstalk exist, which can be undesired coupling effects among channels using fuzzy controllers. The coupling effect that occurs among Power Amplifiers (PAs) causes non-linear crosstalk, which is the number one focus of Fig. 1. To improve the signal greatly, the transmitter must be aware of non-linear crosstalk when assessing linear crosstalk, which happens after PAs and may be adjusted at the receiver aspect.

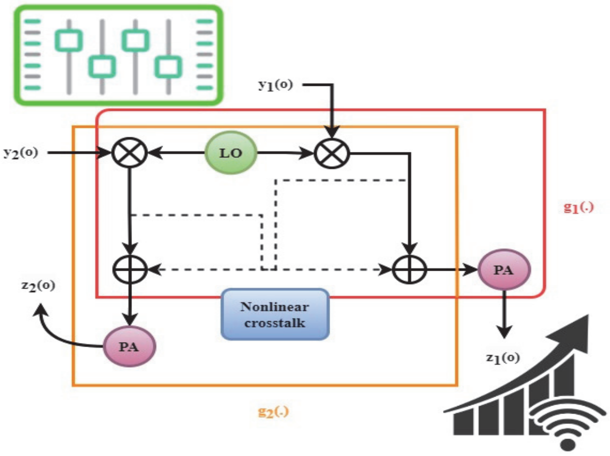

Figure 1 MIMO transmitter non-linear crosstalk and MIMO-DPD compensation

Fig. 1 displays that non-linear crosstalk is present in a 2 × 2 MIMO transmitter association. This phenomenon is more likely to occur when RF alerts leak out of a gadget through a shared Local Oscillator (LO) or when there is not enough separation among physical channels. As a signal travels up the transmitter's better branch, it encounters crosstalk from the lower zone, which distorts the composite sign and causes complex intermodulation products to be generated at the non-linear PA's output. These interactions are the number one reason for the phenomenon.

$$\left[\overrightarrow{i(n)}.\overrightarrow{o(n)}\right]=\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]\begin{bmatrix}\vec{e}_{i1.o1} & \cdots & \vec{e}_{in.on}\\ \vdots & \vdots & \vdots\\ \vec{e}_{in.on} & \cdots & \vec{e}_{in.on}\end{bmatrix} \tag{1}$$

$$\begin{bmatrix}\vec{e}_{i1.o1} & \cdots & \vec{e}_{in.on}\\ \vdots & \vdots & \vdots\\ \vec{e}_{in.on} & \cdots & \vec{e}_{in.on}\end{bmatrix}=\left(1-\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]^{k}\right)\left[\overrightarrow{i(n)}.\overrightarrow{o(n)}\right] \tag{2}$$

To transform the non-linear transmitter and ANP cascade into a linear system, the MIMO models represent the opposite of the non-linear behaviour $\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]$. While directly synthesizing the transmitter's inverse behavioural model $\left(1-\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]^{k}\right)$, the input, as well as the output in the equation, should be exchanged to derive the multi-branch BER coefficients ce. When there are multiple input and output ports, as in a MIMO scenario $\vec{e}_{i1.o1}$, the aforementioned multi-branch structure bm is expanded. Here is an extension of the formula in (1) for the dual-input dual-output framework $\left[\overrightarrow{i(n)}.\overrightarrow{o(n)}\right]$.

$$\begin{bmatrix}\vec{e}_{i1.o1} & \cdots & \vec{e}_{in.on}\\ \vdots & \vdots & \vdots\\ \vec{e}_{in.on} & \cdots & \vec{e}_{in.on}\end{bmatrix}=\left(1-\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]^{k}\right)* \\ \frac{1}{dft}\left[\overrightarrow{i(n)}\left(1-\overrightarrow{o(n)}\right)\right] \tag{3}$$

While the inverse Fourier transform $\frac{1}{dft}$ is not directly dependent on the cross-terms of and in the given Eq. (3), their impacts were considered while identifying the ANP matrix, so their effect already exists in the ANP-DPAL functions and is given as $\left(1-\overline{o(n)}\right)$ for the output function.

With the assistance of this era, it is far more feasible to make it easier to offer applicable repayment for non-linearities and crosstalk in transferred indicators. It has taken a lot of effort and time for researchers to idealize the ILA-based MIMO-DPD fashions to reduce the quantity of distortion and improve the pleasantness of the signal. Figure 1 illustrates the dynamic look of a 2 × 2 MIMO transmitter, which is impacted by non-linear crosstalk inside the community. Crosstalk and non-linearity are two elements that result in a stage of complexity that needs to be considered even when building repayment applications using fuzzy controllers. It is an attractive choice for enhancing the overall performance of MIMO transmitters and resolving issues delivered by using non-linear crosstalk since it uses the ILA technique and emphasizes pre-distortion fashions in MIMO-DPD. As a result of the abundance of sparkling concepts, it is miles positive that research into MIMO verbal exchange structures and repayment techniques will hold to boost toward destiny. The Adaptive Non-linear Pre-Distortion Power Amplifier Linearization (ANP-DPAL) method relies heavily on adaptive filtering algorithms (AFA) to compensate for the non-linearities of power amplifiers (PAs) in realtime. These algorithms constantly check the PA's output and feed that information back into the loop to keep the pre-distortion model running at peak efficiency regardless of the signal's frequency, amplitude, or environmental factors. An AFA improves signal quality and spectrum efficiency by reducing distortion and increasing linearity using advanced algorithms representing memory effects and higher-order non-linearities. In addition, they continuously function at a high level despite variations in temperature, age, and manufacturing variances in PA characteristics. As they allow for efficient and fast processing, AFAs are crucial for current PA linearization when implemented in digital signal processing (DSP) hardware.

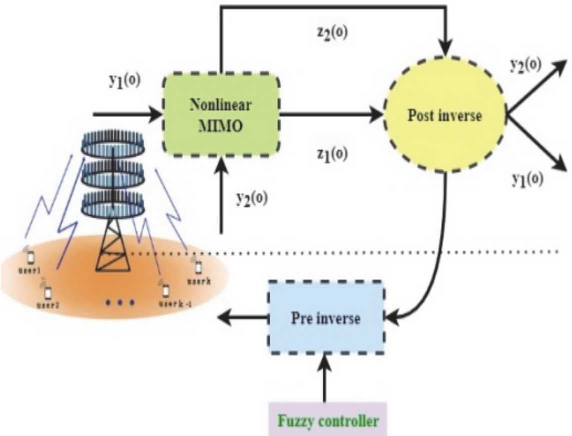

Figure 2 MIMO transmitters with an ILA-based DPD architecture

The structure of a Digital Predistortion (DPD) device for Multiple-Input Multiple-Output (MIMO) transmitters is depicted in Fig. 2. An important concept that underpins the ILA technique is the extraction of the post-inverse price for the non-linear MIMO network and the utilization of this characteristic to estimate the pre-inverse, which features as a predistorter to reduce the amount of non-linearity that is present within the device using a fuzzy controller.

$$CT_{\text{impact}} = \frac{\sum_{x=0}^{1}\left(RF_{tr}.2(CT_{ph}.CT_{ef}.\exp\left(ph.ef\right).(1-e\left(i\left(n\right)+o\left(n\right)\right)\right)+dc\left(tr\right)}{\sum_{y=1}^{k}\left(AB*_{CT_{ph}.CT_{ef}}+\left(1-\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]^{k}\right)\right)} \quad (4)$$

The impact of crosstalk CT_{impact} the MIMO transmitter's performance is investigated by simulating a dual-channel transmitter *dc*. The two RF uplink transmitters RF_{tr} in the simulation configuration stood in for the two transmission routes in the MIMO networks. By connecting the signals in both directions using summation, it can simulate the crosstalk phenomenon *ph* of RF_{tr}. The PAs are supplied with signals that had a crosstalk effect *ef* using Eq. (4). For these models, we consulted the data collected from a class AB PA that made use of the PTF10107 transistor: a memory multi-branch polynomial of $\left(1-\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]^{k}\right)$.

$$Cs = \sum_{x=0}^{1}\left(1-l\left(pa\right).\frac{N_{sp}-P_{bm}}{\left(1-\left[bm_{\overrightarrow{ce1}}.bm_{\overrightarrow{ce2}}\right]^{k}\right)}\right)+bias.\left(\frac{\left|i\left(n\right).o\left(n\right)\right|^{k-1}}{\max\left(pa\right)}\right) \quad (5)$$

To linearize *l* strength amplifiers (PAs), this method consists of first computing the submit-inverse, after which using that cost *Cs* to approximate the pre-inverse. Additionally, configuration into how *PA* performance is affected by phase noise during signal production N_{sp}. Parameter estimates for behavioural modelling P_{bm} and the DPD method includes *bias* factors due to phase noise max(*pa*) using Eq. (5). This adaptive behaviour is made possible by AFAs, which use complex algorithms to fine-tune the pre-distortion model in realtime, guaranteeing accurate compensation for changing signal circumstances. Better signal quality and spectrum efficiency are outcomes of using AFAs for linearization, which allows for more precise and efficient operation. The increasing need for larger data rates and improved signal quality in current communication systems may be effectively met using this real-time flexibility and increased performance, substantially improving over traditional methods.

With its capacity to measure noise, crosstalk disruption, and PA non-linear behaviour, ANP-DPAL shows exquisite promise to improve the pleasantness of alerts and spectrum utilization in contemporary messaging networks. The approach's adaptive pre-distortion in real-time and creative usage of parametric non-linear models display its efficacy and versatility. The simulation consequences show that ANP-DPAL is useful in real-world settings, with widespread profits in sign linearity, distortion decrease, and noise robustness for unique working conditions. Thus, ANP-DPAL is an important step in improving the performance and dependability of MIMO communique systems in many settings.

4 RESULTS AND DISCUSSION

Power amplifier (PA) linearization in Multiple Input Multiple Output (MIMO) systems faces challenges due to non-linearity, transceiver noise, and crosstalk. The Adaptive Non-linear Pre-Distortion for Power Amplifier Linearization (ANP-DPAL) method addresses these challenges with an adaptive pre-distortion module that adjusts input signals in real-time, compensating for non-linearities. This overview compares the effectiveness of ANP-DPAL with other methods, focusing on system performance, spectrum efficiency, signal integrity, signal linearity, and Bit Error Rate (BER). The real-time adjustments entail continuously monitoring the power amplifier's output signal and dynamically adjusting the pre-distortion environments based on this feedback. The system usually uses adaptive filtering algorithms (AFA) to combat non-linear distortions, which modify these parameters effectively. To provide accurate pre-distortion, measurement noise estimation is crucial for detecting and reducing the effect of signal noise. As part of the pre-distortion adjustment procedure, algorithms evaluate the noise level in the feedback signal. Despite changing signal circumstances and measurement noise, ANP-DPAL improves system performance and signal linearity by incorporating these components into the system and ensuring that the pre-distortion model stays accurate and responsive.

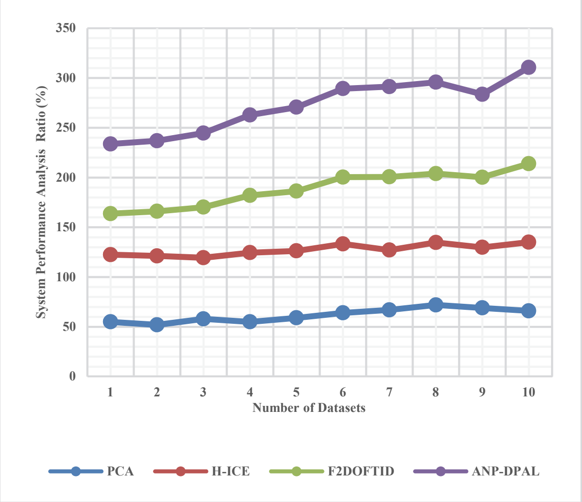

Figure 3a System performance analysis is compared with ANP-DPAL

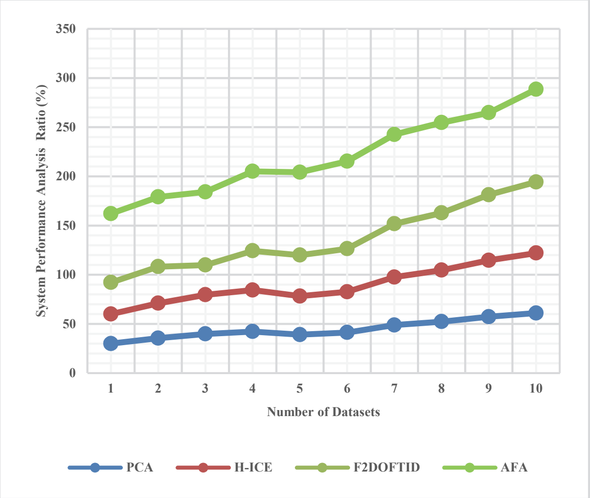

Figure 3b System performance analysis is compared with AFA

Fig. 3a demonstrates that ANP-DPAL achieves a System Performance Analysis score of 96.8%, while Fig. 3b shows that AFA (Adaptive Filtering Algorithm) scores 94.2%, indicating that ANP-DPAL offers superior system performance.

Similarly, in Fig. 4a, ANP-DPAL obtains a Spectrum Efficiency Analysis score of 97.5%, while AFA reaches 93.4% in Fig. 4b, highlighting ANP-DPAL's advantage in spectrum efficiency.

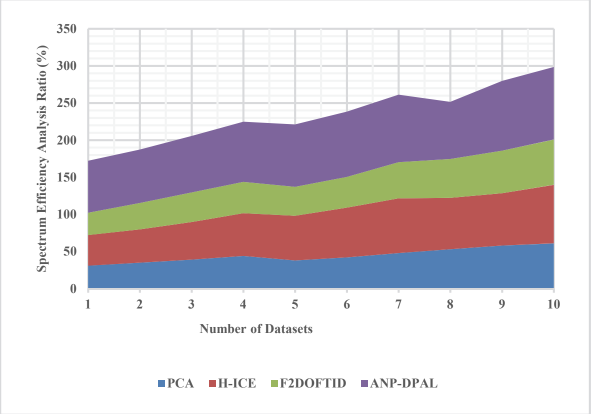

Figure 4a Spectrum efficiency analysis is compared with ANP-DPAL

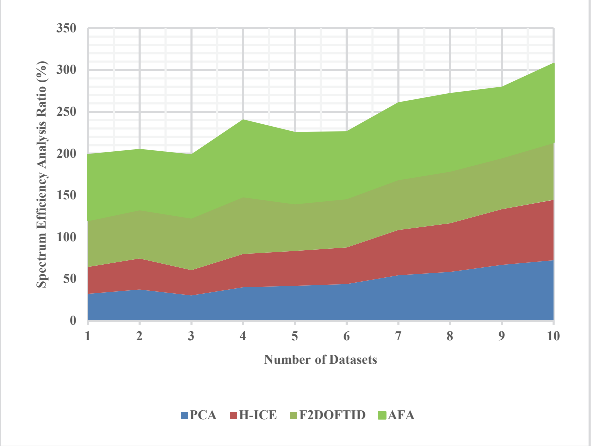

Figure 4b Spectrum efficiency analysis is compared with AFA

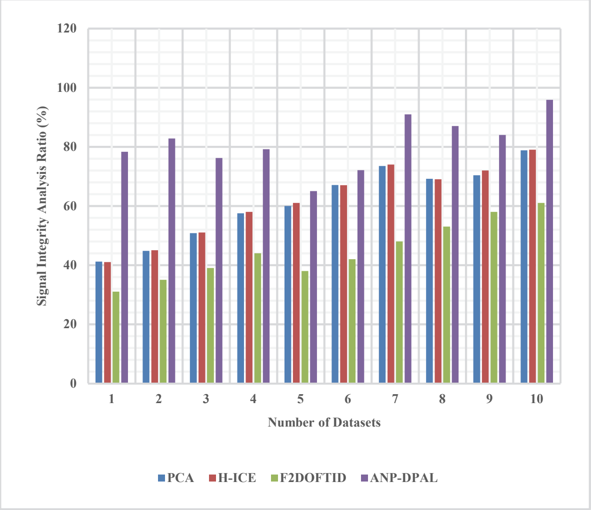

Figure 5a Signal integrity analysis is compared with ANP-DPAL

Regarding signal integrity, Fig. 5a reveals that ANP-DPAL achieves a score of 95.6%, compared to AFA's 90.4% in Fig. 5b. This significant difference indicates

ANP-DPAL's effectiveness in maintaining signal integrity. Compared to other methods like AFA, the results show that ANP-DPAL is the best at maximizing spectrum efficiency.

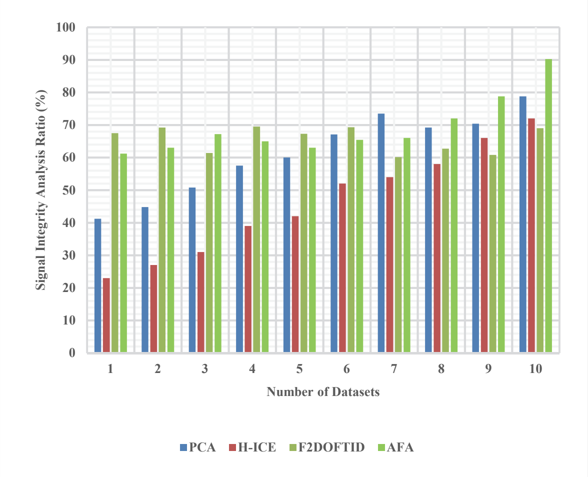

Figure 5b Signal integrity analysis is compared with ANP-DPAL and AFA

Regarding Bit Error Rate (BER), Fig. 6a shows that ANP-DPAL reaches a low rate of 15.7%, while AFA scores 31.6% in Fig. 6b. This illustrates ANP-DPAL's superior performance in reducing bit errors.

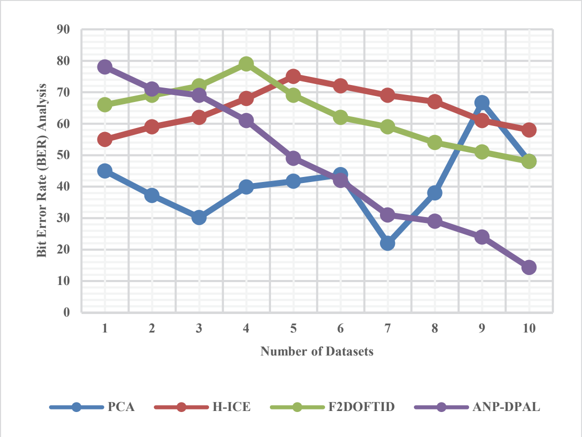

Figure 6a Bit error rate (BER) analysis is compared with ANP-DPAL

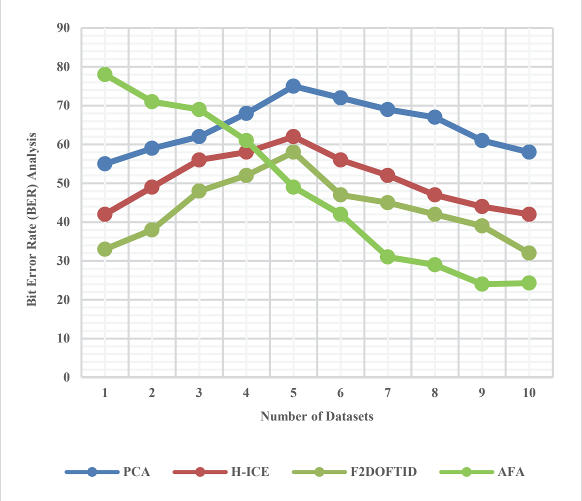

Figure 6b Bit error rate (BER) Analysis is compared with AFA

By efficiently adjusting for memory effects and higher-order non-linearities, ANP-DPAL has shown a greater capacity to linearize the power amplifier output signal. Consequently, the input and output signals become more linear, improving signal quality by decreasing distortion. Bit errors during transmission are usually caused by distortion and interference; ANP-DPAL eliminates these problems by increasing the transmitted signal's linearity. As a result, the BER drops dramatically, which is great for the security and dependability of the network. An important metric for modulation precision and signal quality, EVM, is minimized by ANP-DPAL. Lower EVM values, which indicate improved transmitted signal quality and better adherence to the intended modulation scheme, are achieved by ANP-DPAL by dynamically modifying the pre-distortion environments to offset the non-linearities of the PA.

These results suggest that ANP-DPAL outperforms AFA in multiple key metrics, offering a promising solution for PA linearization in MIMO systems. The findings highlight the importance of ANP-DPAL in improving system reliability, performance, and signal integrity. This suggests that incorporating fuzzy logic principles and controllers could enhance communication technologies by optimizing linearization techniques, reducing errors, and improving robustness against crosstalk and noise.

For practical applications like 5G and the Internet of Things (IoT), ANP-DPAL improves signal quality by reducing distortion and increasing overall performance via dynamic parameter adjustment for pre-distortion. In addition to improving frequency use, it enhances spectrum efficiency by reducing interference from neighbouring channels and out-of-band transmissions. Nevertheless, the need for advanced adaptive filtering algorithms and the ability to analyze data in real-time might make implementing ANP-DPAL more complicated and expensive. To do this, state-of-the-art digital signal processing gear and improvements to preexisting infrastructure may be required. Maintaining constant performance over time requires a system that can withstand variations in power amplifier performance, which factors like temperature fluctuations and device age may cause.

5 CONCLUSIONS

The proposed research on ANP-DPAL addresses key challenges in modern communication networks, emphasizing signal quality and spectrum efficiency. To combat the impact of measurement noise and crosstalk on Power Amplifiers (PAs) in MIMO systems, ANP-DPAL uses a parameterized model to harness inherent non-linearities, allowing real-time input adjustments for robust linearization. This approach uses adaptive filtering algorithms to resolve crosstalk, ensuring accurate channel interference measurement and correction. ANP-DPAL's integration of adaptive filtering algorithms with a dimension-specific noise estimation method enhances noise resistance during linearization. The adaptability of this method makes it suitable for various communication environments, including 5G, wireless local area networks, and satellite communication networks. By incorporating fuzzy logic controllers, ANP-DPAL offers a promising solution for managing noise and crosstalk in MIMO systems. Simulation studies validate the effectiveness of ANP-DPAL, showing significant improvements in linearization, crosstalk reduction, and noise robustness. Metrics like signal linearity, Bit Error Rate (BER), and Error Vector Magnitude (EVM) confirm the technique's potential in real-world applications, indicating its capacity to meet the growing demands for reliable and efficient wireless communication.Future work will enhance the real-time processing capabilities of ANP-DPAL through advancements in digital signal processing (DSP) hardware and software, ensuring that the system can handle the increasing complexity and data rates of modern communication systems.

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