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Duplex Mobile Wireless Communication with Embedded Controller for Feedback Actuation Control

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Abstract
The rapid advancement of wireless communication technologies, combined with the evolution of embedded systems, has paved the way for innovative, real-time control and feedback architectures in mobile and industrial environments. This review presents a comprehensive study on Duplex Mobile Wireless Communication with Embedded Controller for Feedback Actuation Control, focusing on the implementation of full-duplex (FD) systems using embedded platforms such as Arduino, STM32, and Raspberry Pi. The integration of wireless communication (RF, LoRa, Wi-Fi) with embedded controllers allows the realization of compact, energy-efficient, and portable systems capable of real-time bidirectional data exchange. This enables enhanced applications in domains like smart agriculture, industrial automation, IoT, and mobile robotics. The study evaluates performance using various adaptive filtering algorithms—LMS, RLS, and NLMS—on MIMO-OFDM systems to optimize mean square error (MSE) and bit error rate (BER). The proposed NLMS-based system shows significant improvements over existing algorithms in both BER and MSE. Future scopes include the integration of AI, 5G, GPS, and encryption modules for expanded applications in smart cities, defense, and multimedia communication.

Keywords: - Full-Duplex Communication, Embedded Controllers, MIMO-OFDM, NLMS Algorithm, Wireless Feedback Control

1. INTRODUCTION

Cellular communication systems have rapidly evolved from simple analog voice communication systems to more complex digital systems that transfer gigabytes of data every second. Fourth generation (4G) standards, which are globally deployed today, are designed for data-centric networking along with voice communication. They employ several technologies such as multi-input multi-output (MIMO) communication, orthogonal frequency division multiple access (OFDMA), cell densification, and carrier aggregation [1]. However, the emergence of new applications such as e-healthcare, internet of things (IoT), virtual and augmented reality, proximity services based on device-to-device (D2D) communication, and internet of vehicles (IoV) has again necessitated an overhaul of the radio access and backbone networks [2]. This has paved way for the fifth generation (5G) standards.

The performance goals of the cellular systems have evolved and are diverse. The 5G standards need to address three broad goals [3]. Firstly, they need to support a massive network of battery-constrained sensors that transmit at low bit rates. Secondly, they need to support applications such as tactile communication and online gaming that require low latency and highly reliable transmissions. Thirdly, they need to enhance mobile broadband to support applications such as virtual and augmented reality that require high data rates. The 5G systems need to support up to 20 times more data rate than the 4G systems [4]. Millimeter wave communication, massive MIMO, cell densification, and full-duplex (FD) communication are the key technologies that will enable the 5G standards to meet these goals. We discuss them below.

Millimeter Wave Communication: Today's 4G cellular systems operate at carrier frequencies between 700 MHz and 3 GHz. These bands are congested and are not sufficient to support the data rates envisioned in the 5G standards. Millimeter wave bands with carrier frequencies ranging from 30 GHz to 300 GHz offer very large bandwidths that can address this spectrum crunch [5]. Besides offering more bandwidth, the smaller wavelengths of these frequencies reduce the physical dimensions of the transceiver antennas. This allows the space constrained hand-held devices to support more antennas. However, these bands pose several new challenges. Signals in these bands undergo severe attenuation due to penetration loss, atmospheric absorption, and rain-induced absorption. To compensate for these losses, the transmitters and the receivers need to form very narrow beams.

1.1 FD Communication

FD was first introduced in 1949 to eliminate transmit mode to receive mode switching in pulsed radars [13]. These radars switch to the receive mode to detect the reflected signals from the target. In short-range target detection, this switching is impractical because the small round-trip time makes the switching period extremely short. FD completely eliminates the need for

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mode switching by enabling simultaneous reception while the radar is transmitting. In modern wireless communication networks, FD was first implemented in cellular relays, which were specified in the 4G long term evolution (LTE) standard. These relays improve the cell-edge user's quality of service (QoS) by reducing the signal forwarding delay and increasing the throughput [14]. Also, FD is a part of cable modem standard data over cable service interface specifications (DOCSIS) 4.0 released by CableLabs [15]. It enables a peak data rate of 10 Gbps in a hybrid fiber-coaxial (HFC) network. In the cellular networks and WLANs, FD offers several advantages. It increases the throughput and reduces the packet transmission latency [13, 16]. It improves the secrecy since eavesdroppers receive a superimposition of two or more signals that is harder to decode [17]. An FD-capable AP can reduce the packet collisions in a WLAN by sending a busy tone to users that are hidden from the transmitting user [18]. Also, FD can be combined with other technologies such as MIMO and non-orthogonal multiple access (NOMA) [19– 22]. However, FD also creates new challenges in a network. The first challenge is selfinterference (SI) due to power leakage from the closely placed transmitter to the receiver in an FD-enabled device. This is suppressed using advanced software and hardware design approaches. The second challenge is inter-user interference from the simultaneously transmitting user to the receiving user. This is suppressed by intelligent selection of the transmitting and receiving users.

1.2 Motivation

In the modern era of communication, the demand for wireless connectivity is ever- growing, driven by the need for flexibility, portability, and real-time interaction. Traditional wired communication systems, while reliable, pose significant limitations in terms of mobility, installation complexity, and scalability. To address these challenges, wireless communication systems integrated with embedded controllers offer a compelling alternative—especially in mobile environments where seamless, two-way communication is essential.

The motivation behind this project stems from the increasing need for efficient and portable communication systems that can operate in dynamic and remote conditions. Whether it is disaster recovery operations, military communications, industrial automation, or smart agriculture, the ability to communicate in real-time without dependence on fixed infrastructure is invaluable. In such scenarios, duplex communication—where devices can simultaneously send and receive data—enhances the effectiveness and responsiveness of the system.

Embedded controllers such as Arduino, STM32, or Raspberry Pi offer the capability to process and control data at the edge, making systems smarter and more autonomous. By combining these microcontrollers with wireless transceivers (like RF, LoRa, or Wi-Fi modules), it becomes possible to create lightweight, energy- efficient, and cost-effective communication devices. This integration also supports the development of compact, mobile units suitable for field operations, where portability and robustness are key.

Another strong motivator is the growing focus on Internet of Things (IoT) and machine-to-machine (M2M) communication, where billions of devices need to interact seamlessly. Duplex wireless communication is a foundational element in such systems, enabling bidirectional data flow for control, feedback, and monitoring. Implementing such a system using embedded controllers not only reduces cost but also provides flexibility for customization, making it ideal for research, prototyping, and real-world deployment.

1.3 Objective of the Research

The objective of this project is to design and implement a duplex (two-way) wireless communication system that utilizes an embedded controller to enable real-time, mobile, and efficient data exchange between two devices or nodes. The system aims to support seamless communication in both directions (transmit and receive) using wireless technologies, while the embedded controller manages control logic, signal processing, and data routing to ensure portability, reliability, and automation for applications such as remote monitoring, robotics, smart agriculture, and IoT-based systems.

- To study and to analyse the performance of forthcoming future generation wireless networking technique i.e. WiMAX as the upcoming 5G standard for meeting the requirements of last mile end to end wireless network with greater system capacity and with improved bit error rate.
- To model the complete wireless communication is the adaptive channel estimation (CE) where the channel is rapidly time varying.
- To study the various types of modulation techniques and adaptive algorithm for transmitter and receiver antenna of wireless communication i.e. effects of mean square error (MSE) and bit error rate (BER).
- Real time data implementation in WiMAX system by real time transmitting and receiving the signals such as image and speech inputs.

- The achievement of improved WiMAX system performance under real time data scenario with the implementation of antenna diversity techniques.

2. MIMO-OFDM SYSTEM

In radio, various information and numerous yield, or MIMO, is the utilization of different reception apparatuses at both the transmitter and collector to enhance correspondence execution. The terms info and yield allude to the radio channel conveying the flag, not to the gadgets having receiving wires. MIMO innovation has pulled from consideration in remote interchanges, since it offers huge increments in information throughput and connection extend without extra data transfer capacity or expanded transmit control. It accomplishes this objective by spreading a similar aggregate transmit control over the radio wires to accomplish a cluster pick up that enhances the ghostly productivity (more bits every second per hertz of data transmission) as well as to accomplish a differing qualities pick up that enhances the connection dependability (lessened blurring). As a result of these properties, MIMO is a critical piece of current remote correspondence principles, for example, IEEE 802.11n (Wi-Fi), 4G, Wi-MAX and so on. MIMO can be sub-partitioned into three principle classes, pre-coding, spatial multiplexing or SM, and differing qualities coding.

2.1 Wireless Communication

Wireless communication is defined as the transfer the information between two or more devices without any electrical or wire connections. Wireless communication systems have increased the throughput over channels and networks. At the same time the reliability of wireless communication has been increased. The main force behind wireless communication is the promise of portability, mobility and accessibility.

Remote correspondence is a standout amongst the liveliest ranges in the corresponding field today. While it has been a point of study since the 1960s, the previous decade has seen a surge of research exercises in the region. This is because of a juncture of a few elements. To begin with, there has been a hazardous increment sought after for tie less availability, driven so far for the most part by cell communication yet anticipated that would be soon overshadowed by remote information applications. Second, the sensational advance in VLSI innovation has empowered little region and low-control execution of modern flag handling calculations and coding systems. Third, the achievement of the second - era (2G) computerized remote guidelines, specifically, the IS-95 Code Division Multiple Access (CDMA) standard, gives a solid show that smart thoughts from correspondence hypothesis can have a noteworthy effect practically speaking. The exploration push in the previous decade has prompted to a much wealthier arrangement of points of view and devices on the most proficient method to convey over remote channels, and the photo is still particularly developing. There are two crucial parts of remote correspondence that make the issue testing and fascinating.

2.2 Wimax

WiMAX alludes to interoperable executions of the IEEE 802.16 group of remote systems models approved by the WiMAX Forum. (So also, Wi-Fi alludes to interoperable executions of the IEEE 802.11 Wireless LAN benchmarks affirmed by the Wi-Fi Alliance.) WiMAX Forum confirmation permits merchants to offer settled or versatile items as WiMAX guaranteed, accordingly guaranteeing a level of interoperability with other ensured items, the length of them fit a similar profile. It is a media communications innovation that gives remote information in an assortment of courses, from indicates guide joins toward full versatile cell sort get to.

- The first IEEE 802.16 standard (now called "Settled WiMAX") was distributed in 2001. WiMAX received some of its innovations from WiBro, an administration promoted in Korea.
- Versatile WiMAX (initially in light of 802.16e-2005) is the amendment that was conveyed in numerous nations, and is the reason for future corrections, for example, 802.16m-2011.
- WiMAX is once in a while alluded to as "Wi-Fi on steroids" and can be utilized for various applications including broadband associations, cell backhaul, hotspots, and so forth. It is like Wi-Fi, however, it can empower utilization at much more noteworthy separations.

2.3 IEEE (Standards)

The Institute of Electrical and Electronics Engineering (IEEE) is one of the biggest social orders of specialists and researcher to enhance development and innovative perfection in the field of electrical, gadgets and all related branches of various orders and applied sciences. The IEEE is the significant open door supplier of learning in building discipline like research, science and innovation. They get the level of fundamental distributers of diaries and research meetings. The IEEE is arranged in the city of United States of America in New York. The IEEE society appeared in the year 1963 in New York (USA). By incorporating these two associations Institutes of radio Engineers (IRE shaped in 1912), and the American Institute of electrical Engineers (AIEEE framed in 1884).

An organization with the advancement in Electronics and in 1930 Electronics Engineers turn out to be a piece of the IRE, while the AIEEE is connected with light, control frameworks and broadcast communications. The IEEE involves thirty nine unique social orders, the IEEE standard affiliation is in charge of setting up the standard of IEEE exercises.

2.4 OFDM

Orthogonal frequency division multiplexing (OFDM) is a technique of computerized adjustment in which the information stream is part into N parallel surges of decreased information rate with each of them transmitted on isolated subcarriers. To put it plainly, it is a sort of multicarrier computerized specialized strategy. OFDM has been around for around 40 years and it was initially considered in the 1970s amid research into minimizing impedance among diverts close to each other in recurrence [2].OFDM has appeared in such unique places as deviated DSL (ADSL) broadband and advanced sound and video communicates. OFDM is likewise effectively connected to a wide assortment of remote correspondence because of its high information rate transmission capacity with high transfer speed, productivity and its strength to multi-way delay.

OFDM has been proposed as a transmission strategy to bolster fast information transmission over remote connections in multipath situations. Amid the most recent forty years, OFDM has formed into a well-known plan for wideband advanced correspondence, whether remote or over wires, utilized as a part of utilizations, for example, computerized TV and sound telecom, remote systems administration and broadband web get to. In remote situations, transmitted signs take after a few proliferation ways. At the point when reflected from encompassing articles these ways achieve the beneficiary with various proliferation postpones that causes defer spread, between image obstruction (ISI), blurring, and arbitrary stage bending. For instance, the postponed duplicates of the transmitted flag will meddle with ensuing signs, bringing about the ISI. The transmitted image rate is accordingly restricted by the defer spread of the channel.

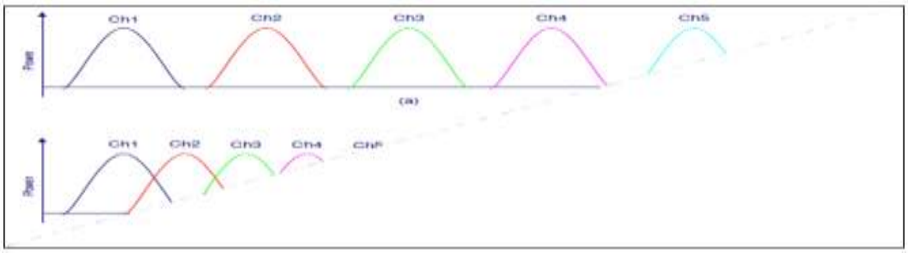

Figure 2.1: Comparison between conventional FDM (a) and OFDM (b)

Figure 2.1 shows the comparison frequency division multiplexing (FDM) and orthogonal frequency division multiplexing (OFDM). It is clearly that the OFDM system provide 40-50% bandwidth saving as compared to FDM system.

2.5 Overview of MIMO

MIMO has been created for a long time for remote frameworks. One of the most punctual MIMO to remote correspondences applications came in mid-1980 with the achievement improvements by Jack Winters and Jack Saltz of Bell Laboratories [9]. They attempted to send information from numerous clients on a similar recurrence/time channel utilizing different radio wires both at the transmitter and recipient. From that point forward, a few scholastics and architects have made noteworthy commitments in the field of MIMO. Presently MIMO innovation has stirred intrigue due to its conceivable applications in advanced TV, remote neighborhood, metropolitan zone systems and versatile correspondence. Contrasting with the Single-information single-yield (SISO) framework MIMO gives upgraded framework execution under a similar transmission condition. To begin with, MIMO framework extraordinarily builds the channel limit, which is in relative to the aggregate number of transmitter and beneficiary clusters. Second, MIMO framework gives the upside of spatial assortment: every one transmitting sign is distinguished by the entire identifier exhibit, which enhanced framework strength and dependability, as well as diminishing the effect of ISI (bury image obstruction) and the channel blurring since every flag assurance depends on N recognized outcomes.

3. PROPOSED METHODOLOGY

Generally in most of the live applications and in the environment information of related incoming information statistic is not available at that juncture adaptive filter is a self-regulating system that takes the help of a recursive algorithm for processing. Moreover, it is self-regulating filter which uses some training vector that delivers various comprehensions of a desired response can be merged with reference to the incoming signal. First input and training is compared accordingly error signal is generated and that is used to adjust some previously assumed filter parameters under the effect of incoming signal. Filter parameter adjustment continues until steady state condition.

As far as application of noise reduction for speech is concerned, adaptive filters can give better performance. Reason for that noise is somewhat similar to the randomly generates signal and every time it's very difficult to measure its statistic. Design of fixed filter is completely failed phenomena for continuously changing noisy signal with the speech. Some of the signal changes with very fast rate in the context of information in the process of noise cancellation, which requires the help of self- regularized algorithms with the characteristics to converge rapidly. LMS and RLS are generally used for signal enhancement as they are very simple and efficient. This chapter analyses the performance of LMS and RLS and proposed NLMS algorithm in terms of convergence speed, mean square error (MSE) and bit error rate (BER).

3.1 Optimum Linear Filtering Problem

To minimize the mean square value of the of the error signal which is nothing but the difference between the desired response and the actual filtered output this is one the big problem faced in adaptive filter theory and this is called as filter optimization problem. The idea is to design the LTI W (i) filters that are based on a reference signal or input signal X (i) in turn produces output signal.

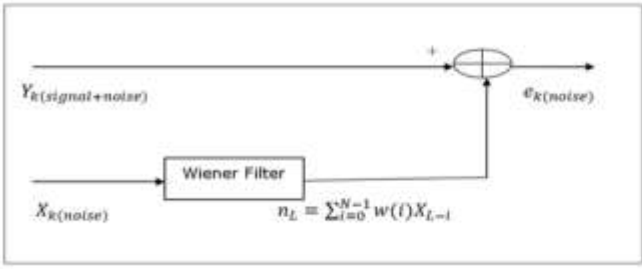

Figure 3.1: Block Diagram of Basic Wiener filter

3.2 Adaptive Filters

Adaptive filter is a digital filter with self-adjusting characteristics and adapts automatically to change in input signals when the input is non-stationary. The Adaptive filter with noise canceller consists of two distinct parts one is digital filter with adjustable coefficients and adaptive algorithm to adjust the coefficients. We are considering that the desired signal (d) is corrupted and our aim is to eliminate the undesired part of this we use adaptive filter. We use adaptive algorithms which provide a set of taps. This tap weights could be implemented and inverted and applied to the received signal. There are three major types of adaptive configurations they are Adaptive noise or echo cancellation adaptive system identification, linear predictive coding all these are similar in algorithms but with different system structure. Because of guaranteed stability and simplicity FIR filters are mostly used over IIR filters. In the above figure the two signals are applied to the filter i.e. Xk , Ok here these both are correlated then the wiener filter produces the optimal estimate of part of subtracts from Xk to produce the ek.

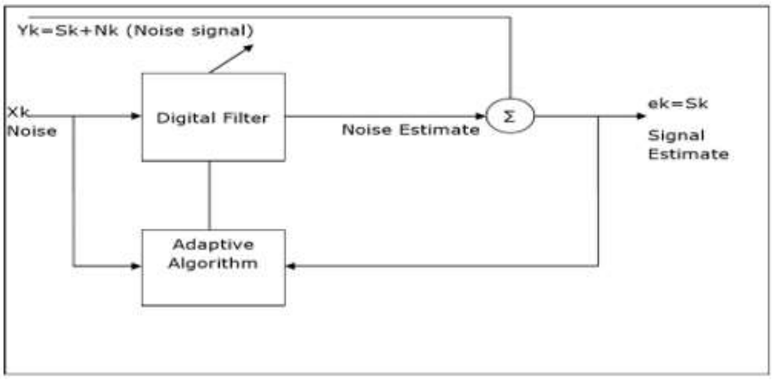

Figure 3.2: Block diagram of Adaptive Filter as a noise canceller

3.3 Proposed System Model

The block diagram for the overall IOT embedded digital ammeter and the Android phone APIs is as shown in Figure 3.2. Arduino Integrated Design Environment (IDE) was used to program Arduino Atmega 2560 microcontroller which controls input and outputs of the microcontroller in C language. In the program, the microcontroller reads the time and date stamp from the EEPROM of a real time clock (RTC) module. Then, a 10-bit analog to digital contoroller in the microcontroller converts the analog signals send from the ACS 172 dc current sensor to the digital value between 0-1023. The sensor was connected to the DUT to read the current supplies to the DUT. With the digital values, the microcontroller verifies if the current read is within the pass current range. If the current is not within the set limit range, the Red LED will be ignited and vice versa for the Green LED.

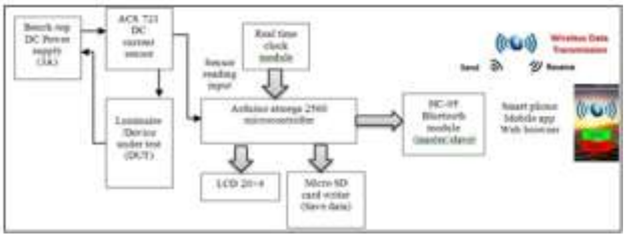

Figure 3.3: FD Microcontroller embedded wireless transmission system

The main motivation behind using the adaptive filter for speech processing is good localization in time and frequency domain. Adaptive filter is the functions suited to the expansion of non-stationary continuous signals.

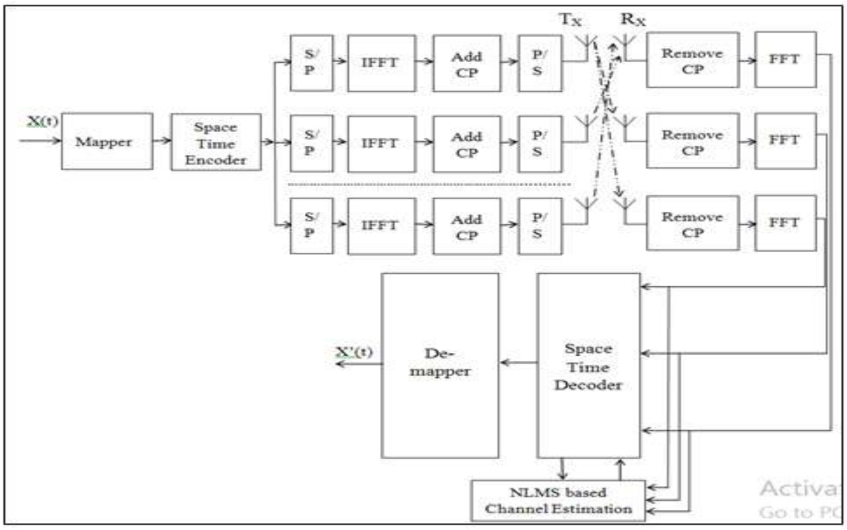

Figure 3.4: Massive System Models with Adaptive Filter

4. RESULT AND DISCUSSION

MATLAB has structured data types. Since all variables in MATLAB are arrays, a more adequate name is "structure array", where each element of the array has the same field names. In addition, MATLAB supports dynamic field names (field lookups by name, field manipulations, etc.). Unfortunately, MATLAB JIT does not support MATLAB structures; therefore just a simple bundling of various variables into a structure will come at a cost.

When creating a MATLAB function, the name of the file should match the name of the first function in the file. A Valid function names begin with an alphabetic character, and can contain letters, numbers, or underscores. Functions are also often case sensitive.

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This dissertation provides a comprehensive introduction to the basic theory and practice of wireless channel modeling, OFDM, and MIMO, with MATLAB programs to simulate the underlying techniques on MIMO-OFDM systems.

4.1 Challenges in Simulation

The biggest challenge in adaptive filter channel estimation technique in Massive system is the switching of the transmitter and receiver antenna elements at the convergence speed. Well, if MIMO is used with OFDM or other multicarrier systems, the complexity and switching requirements may increase further.

In the former case, spatial modulation can be performed digitally and can therefore be implemented independently for each subcarrier in OFDM. Note that one can also use the antennas for conventional beamforming techniques instead in this case. The performance gain is roughly log_2(M) with both techniques so spatial modulation will not provide any extraordinary improvements over conventional techniques in this case.

4.2 Result

4.2.1 LMS Algorithm

The mean square error (MSE) performances of the aforementioned LMS algorithm are explored by performing extensive MATLAB simulations.

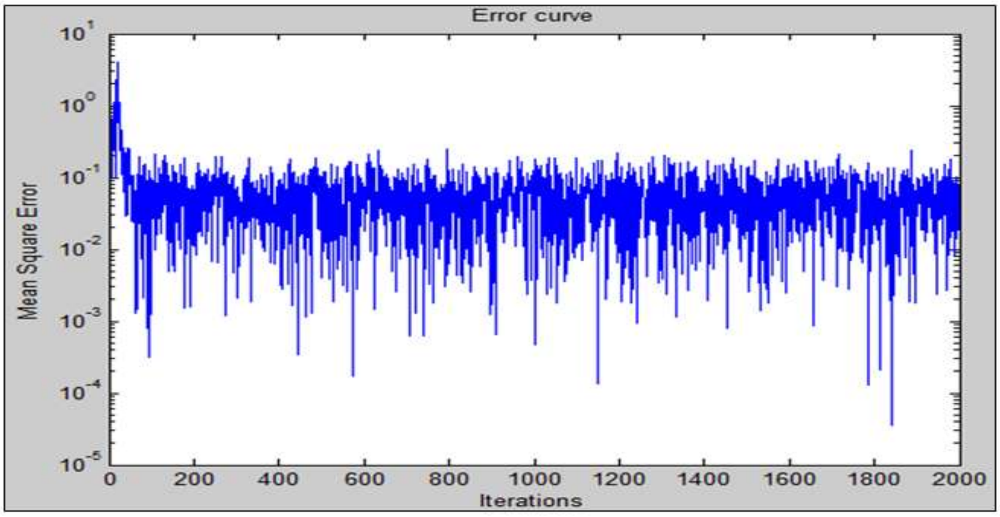

Figure 4.1: Performance of MSE in LMS algorithm

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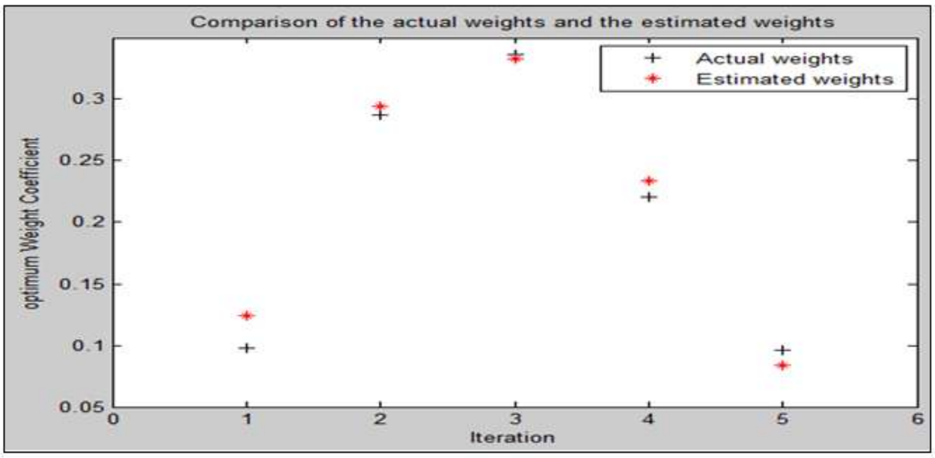

Figure 4.2: Comparison of the actual weights and the estimated weights

Performance of the mean square error (MSE) of the iteration 0-2000 in LMS algorithm is shown in figure 4.1. In this simulation, we consider system output, actual weight and estimation weight and MSE. First the MSE versus iteration has been investigated and the results are shown in Figure 4.2.

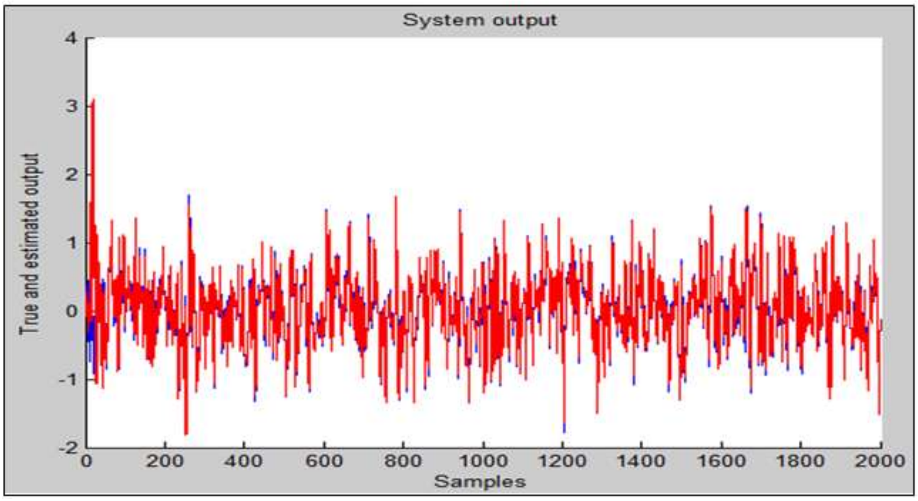

Figure 4.3: Comparison of the true and estimated output

Comparison of the true and estimated output of LMS algorithm is shown in figure 4.3. In this figure blue color shows the true value of the LMS algorithm and red color show the estimated value of the LMS algorithm.

4.2.2 RLS Algorithm

The mean square error (MSE) performances of the aforementioned RLS algorithm are explored by performing extensive MATLAB simulations.

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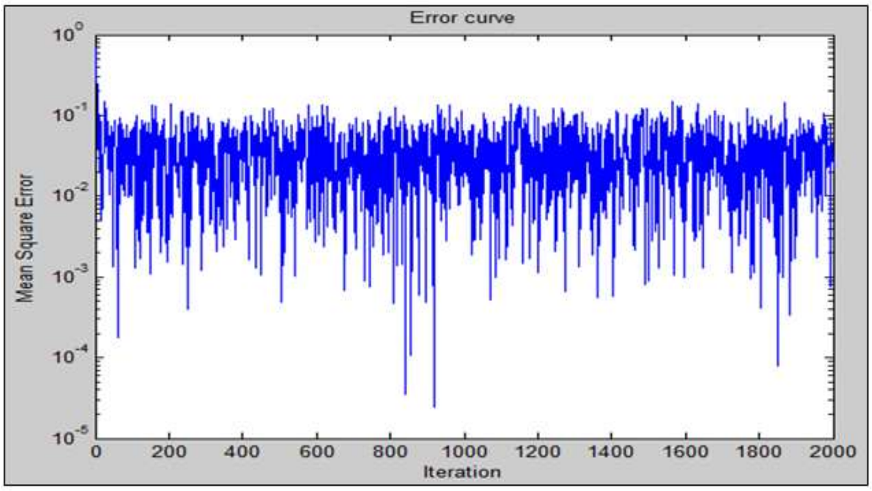

Figure 4.4: Performance of MSE in RLS algorithm

The performance of the mean square error (MSE) of the iteration 0-2000 in RLS algorithm is shown in figure 4.4. In this simulation, we consider system output, actual weight and estimation weight and MSE. First the MSE versus iteration has been investigated and the results are shown in Figure 4.4.

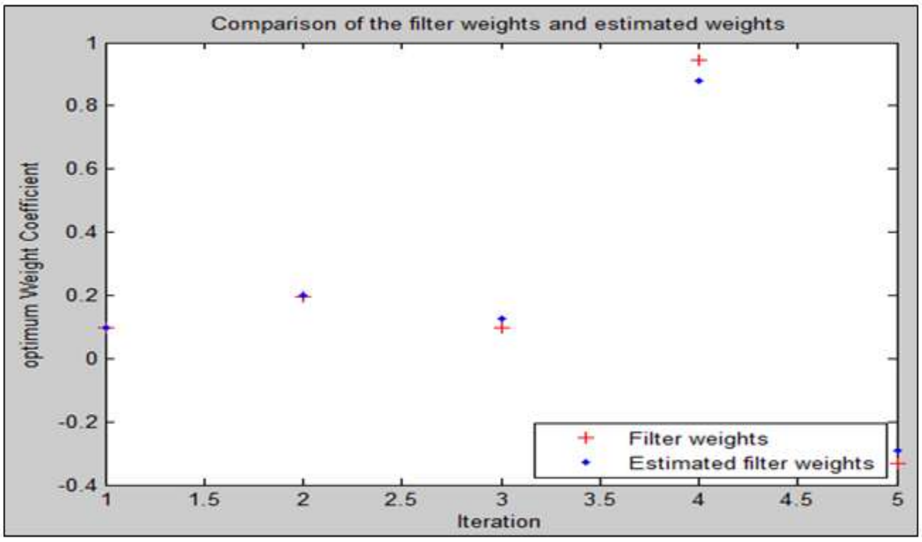

Figure 4.5: Comparison of the actual weights and the estimated weights of RLS

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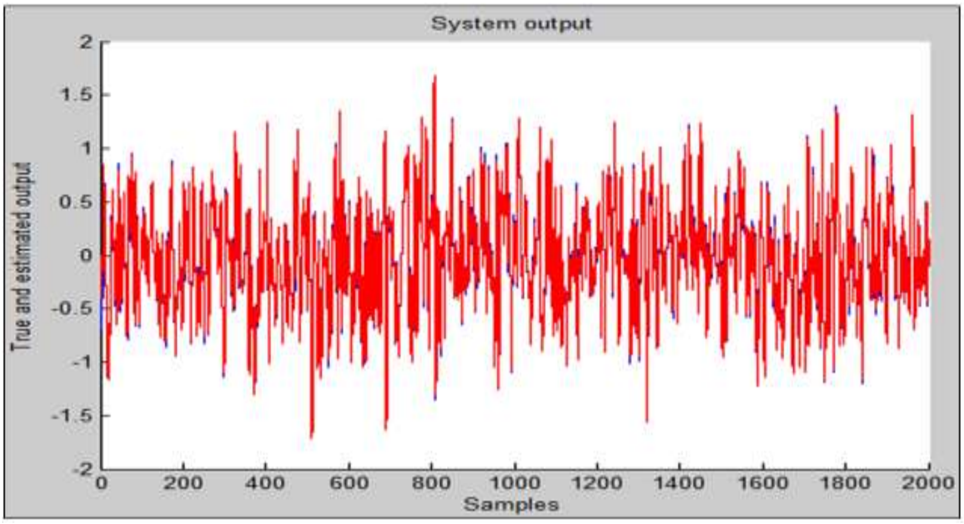

Figure 4.6: Comparison of the true and estimated output of RLS

Figure 5.5 shows the comparison of the actual weight and estimated weight of the RLS algorithm. Red color shows the filter weights of the RLS algorithm and blue color shows the estimated filter weight of the RLS algorithm. Comparison of the true and estimated output of RLS algorithm is shown in figure 5.6. In this figure blue color shows the true value of the RLS algorithm and red color show the estimated value of the RLS algorithm.

4.2.3 NLMS Algorithm

The mean square error (MSE) performances of the aforementioned NLMS algorithm are explored by performing extensive MATLAB simulations.

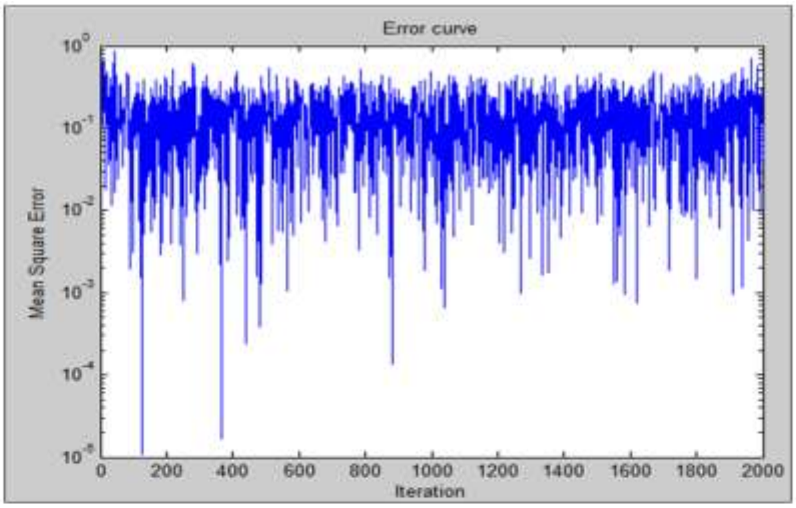

Figure 4.7: Performance of MSE in NLMS algorithm

In this simulation, we consider system output, actual weight and estimation weight and MSE. First the MSE versus iteration has been investigated and the results are shown in Figure 5.7.

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Figure 4.8 shows the comparison of the actual weight and estimated weight of the NLMS algorithm. Red color shows the filter weights of the NLMS algorithm and blue color shows the estimated filter weight of the NLMS algorithm.

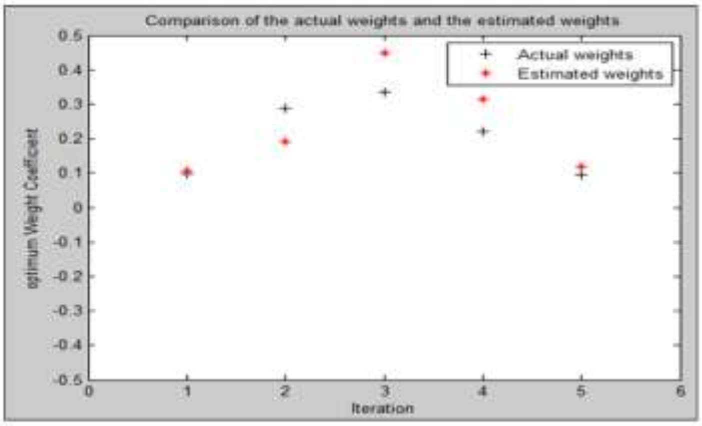

Figure 4.8: Comparison of the actual weights and the estimated weights of NLMS

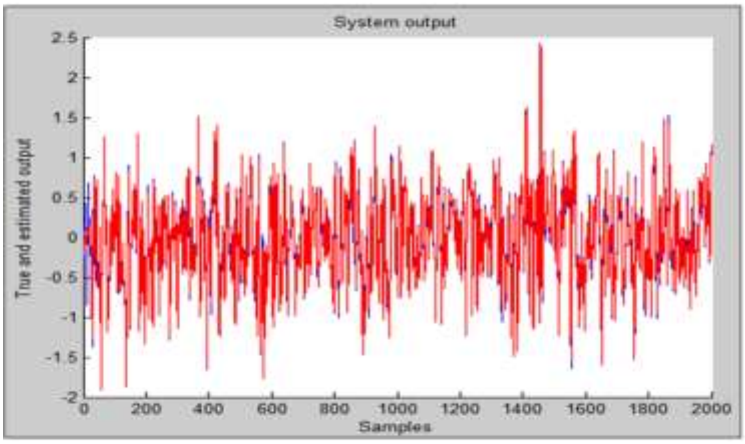

Figure 4.9: Comparison of the true and estimated output of NLMS

Comparison of the true and estimated output of RLS algorithm is shown in figure 4.9. In this figure blue color shows the true value of the NLMS algorithm and red color show the estimated value of the NLMS algorithm.

Table 4.1 shows the value of bit error rate (BER) for LMS, RLS and NLMS algorithm. It is clearly shown that when energy / bits is increasing then there is an increment in the BER in all these algorithms.

Table 4.1: Show the table of different value of BER

BER (dB)			
Eb/ N0(dB)	**LMS**	**RLS**	**NLMS**
10-^{1}	1	1	1
5.5×10^{-1}	3	3	3
10^{-2}	6	6	5.9
5.5×10^{-2}	7	6.9	6.7
10^{-3}	8.1	8	7.8
10^{-4}	12	11	10.5

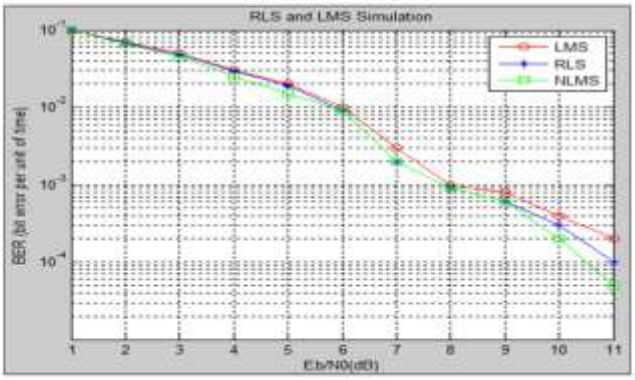

Figure 4.10: Performance BER in LMS, RLS and NLMS Algorithm

The BER and MSE performances of the aforementioned NLMS adaptive receiver are explored by performing extensive computer simulations. In these simulations, we considered 2x2 MIMO-OFDM system. The data symbol is based on BPSK modulation. Various values of the NLMS algorithm's step size have been used. The signal to noise ratio is 15 dB. First the BER performance of using different fixed step- sizes has been investigated and the results are shown in Figure 4.10.

Table 4.2 shows the value of mean square error (MSE) in LMS, RLS and NLMS algorithm. It is clearly that energy / bits are increase than increase the MSE in these algorithm. Compared LMS, RLS and NLMS algorithm, it is clearly that the NLMS algorithm is best result compared to other algorithm.

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Table 4.2: Show the table of different value of MSE

MSE (dB)			
Eb/ N0(dB)	**NLMS**	**RLS**	**LMS**
10^{-2}	1	1	1
5.5×10^{-2}	8	9.4	10.3
10^{-3}	13.3	14	16

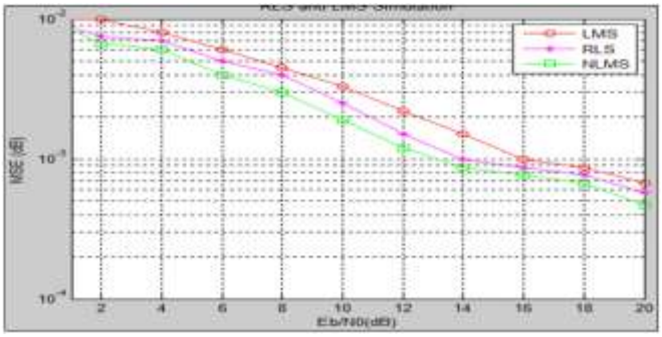

Figure 4.11: Performance MSE in LMS, RLS and NLMS Algorithm

Also the MSE and BER performances of utilizing the NLMS algorithm have been tested and compared with both the RLS and LMS algorithms.

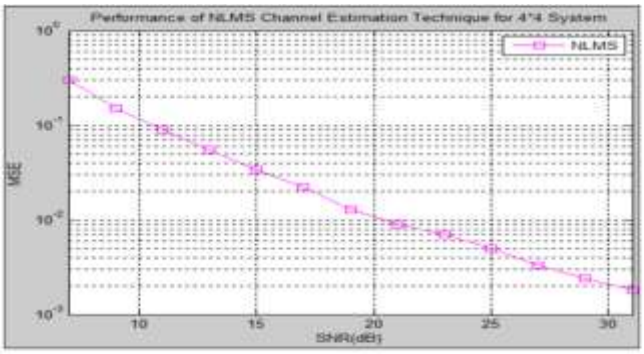

Figure 4.12: Performance MSE for 4×4 MIMO-OFDM Systems

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The results of the MSE performance are presented in Figure 4.11, which show that the NLMS convergence speed is faster with lower steady state noise level compared with the RLS algorithm.

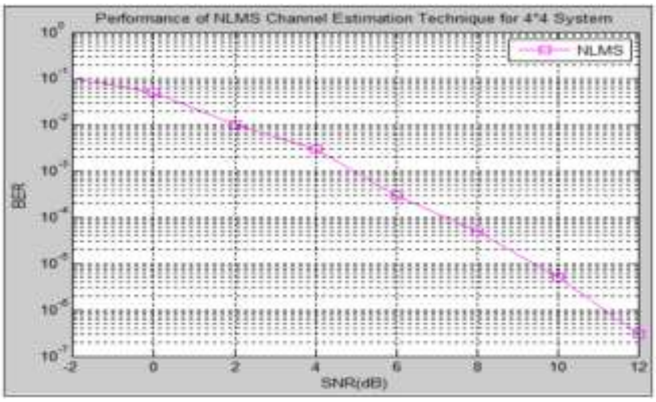

Figure 4.13: Performance BER for 4×4 Massive Systems

Table 4.3: Comparison of BER in Different Channel Estimation Technique for 4×4 System

SNR	Previous Technique	Proposed Technique
	IDMA based Channel Estimation Technique	NLMS based Channel Estimation Technique
-2	0.14	0.08
0	0.07	0.04
2	0.022	0.012
4	0.006	0.004
6	0.001	0.0006
8	0.0009	0.000049
10	0.000008	0.0000038
12	0.0000008	0.0000004

Table 4.4: Comparison Result

S. No.	Parameters	Previous Work	Present Work
1.	Algorithm Used	MIMO-OFDM System using LMS and RLS Algorithm	MIMO-OFDM System using NLMS Algorithm

2.	BER	12 dB	10.5 dB
3.	MSE	16 dB	13.3 dB
4.	Complexity	$4N^2$	3N +1
5.	Compatibility	Poor	Good
6.	Performance	Good	Better
7.	Eb/No	Low	High
8.	Stability	Stable	Good Stable

5. CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

The development of a duplex mobile wireless communication system using embedded controllers marks a significant step toward building flexible, real-time, and portable communication frameworks suited for a variety of modern applications. This project has explored and implemented the concept of full-duplex communication, enabling simultaneous data transmission and reception between two mobile units. With the help of microcontrollers and wireless communication modules, a compact and energy- efficient system has been designed, fulfilling the core objectives set at the beginning of the project.

Throughout the project, embedded controllers such as Arduino or Raspberry Pi have played a crucial role in processing, managing, and controlling the data flow between the two units. These controllers have allowed us to implement custom communication protocols, control user inputs and outputs, manage power efficiently, and enable real- time responses. The use of wireless modules like RF, Zigbee, or LoRa has demonstrated how short-to-long-range communication can be achieved with minimal infrastructure, which is particularly beneficial in remote or infrastructure-less areas.

One of the core achievements of this project is the successful establishment of duplex communication, which enhances overall system performance. Unlike simplex or half- duplex systems, duplex communication provides a more natural and seamless interaction between devices, especially important in applications requiring constant monitoring and immediate feedback, such as smart surveillance, military coordination, or emergency response systems.

The modular design of the system ensures that it can be easily scaled or adapted for various use cases. For instance, by integrating sensors or actuators, the same communication framework could be used in industrial automation, smart agriculture, or environmental monitoring. Additionally, the inclusion of displays, keypads, and status indicators has allowed for an intuitive user interface, making the system user- friendly and practical for field deployment.

The mean square error (MSE) and bit error rate results are obtained for the proposed adaptive channel estimation for MIMO-OFDM system using NLMS algorithm and previous adaptive channel estimation for MIMO-OFDM system using RLS algorithm. From the result analysis of the results, it is found that the proposed adaptive channel estimation for MIMO-OFDM system using NLMS algorithm gives 14 dB mean square error and 10.8 bit per unit of time bit error rate as compared with previous adaptive channel estimation for MIMO-OFDM system using RLS algorithm gives 16 dB mean square error and 11 bit per unit of time bit error rate. So overall performance of the proposed system is consuming 12.5% bit error per unit of time and 4.5% improvement of mean square error.

5.2 FUTURE SCOPE

The proposed system of duplex mobile wireless communication using embedded controllers offers a strong foundation for numerous advanced applications in the fields of wireless communication, automation, and the Internet of Things (IoT). In the future, the system can be enhanced with advanced wireless technologies such as 5G, Bluetooth Low Energy (BLE), or Wi-Fi 6 to achieve higher data rates, lower latency, and improved network capacity.

Integration with GPS and GIS modules can allow location-based communication, which is useful in smart transportation systems, military field operations, and disaster management. The addition of encryption algorithms will enhance security, making the system suitable for transmitting sensitive data. The system can also be scaled to support mesh networking, where multiple nodes communicate seamlessly in a self- healing network, enabling reliable communication in larger areas.

Artificial intelligence and machine learning can be integrated to make the communication intelligent—capable of learning patterns and optimizing signal strength and routing dynamically. Moreover, the system can evolve to support voice and video communication, making it more versatile for multimedia applications. Thus, the future of this project lies in its adaptability and scalability across various domains like smart cities, agriculture, healthcare, and defense systems.

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