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Progress Through Education

DEPARTMENT OF
ELECTRONICS AND COMMUNICATION ENGINEERING

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VISION

“TO BE A CENTRE OF EXCELLENCE IN ELECTRONICS AND COMMUNICATION ENGINEERING THROUGH VALUE-BASED EDUCATION AND RESEARCH”

MISSION

M1: *TO PROVIDE STUDENTS STATE-OF-THE-ART ACADEMIC AMBIANCE FOR QUALITY EDUCATION.*

M2: *FACILITATE INTERDISCIPLINARY LEARNING, INDUSTRY INTERACTIONS AND RESEARCH INITIATIVES FOR LONG TERM CAREER DEVELOPMENT GOALS.*

M3: *TO EDUCATE AND MENTOR STUDENTS ON PROFESSIONAL RESPONSIBILITIES, ETHICAL VALUES AND LIFELONG LEARNING.*

DR. EDAVALATH KAKKAT JANAKI AMMAL

Dr. Edavalath Kakkat Janaki Ammal (4 November 1897 – 7 February 1984) was a pioneering Indian botanist and cytogeneticist, born in Thalassery, Malabar District, Kerala, India. She lived to the age of 86 years. Born into a socially and economically disadvantaged background, she overcame strong caste and gender bias to become an internationally respected scientist.

She was the first Indian woman to earn a PhD in Botany in the USA and played a key role in developing high-yield sugarcane varieties, helping India achieve self-sufficiency in sugar production. Dr. Janaki Ammal also served as the first woman Director-General of the Botanical Survey of India and was honoured with the Padma Shri in 1977 for her outstanding contributions to science.

Principal’s Message

It is a matter of great pride and satisfaction to present the sixth edition of WISSEN 6.0, the technical magazine of the Department of Electronics and Communication Engineering. This publication stands as a testament to the department’s unwavering commitment to academic excellence, skill development, and innovation.

The Department of Electronics and Communication Engineering has made remarkable progress in academics, research, technological advancements, and co-curricular activities. I am confident that this edition of the magazine showcases the achievements and talents of our students and also serves as a valuable reference for faculty members, students, and all those interested in technical education and technology-driven initiatives.

I extend my heartfelt congratulations to the Head of the Department, faculty members, and students for their dedicated efforts in bringing out this edition. The active participation of students in co-curricular and extracurricular activities, combined with their strong academic focus, is truly commendable. Their enthusiasm for learning and knowledge-sharing will undoubtedly help shape them into competent and responsible professionals, ready to contribute meaningfully to the ever-evolving technological landscape.

I wish WISSEN 6.0 great success and hope it continues to inspire and enlighten its readers with every edition.

Happy Reading.

Regards,

Dr. Sunitha C
Principal
Vidya Academy of Science & Technology

HoD's Message

It gives me great pleasure to present the sixth edition of *Wissen 6.0*, the technical magazine of the Department of Electronics and Communication Engineering. This edition stands as a reflection of the intellectual curiosity, innovative thinking, and technical competence nurtured within our department.

In an era of rapid technological advancement, the field of Electronics and Communication Engineering continues to play a pivotal role in shaping modern society. Through this magazine, our students and faculty have showcased their insights, research interests, and creative ideas across diverse and emerging domains, demonstrating their readiness to meet future engineering challenges.

I commend the editorial team and contributors for their dedicated efforts in bringing together this enriching collection of articles and technical content. I also express my sincere appreciation to the college management for their constant encouragement and support in all academic and co-curricular initiatives.

I hope *Wissen 6.0* serves as a source of knowledge, inspiration, and motivation for our readers. May it encourage young minds to think innovatively, explore new horizons, and strive for excellence in their professional journey.

Warm regards,

Dr. S. Swapna Kumar
Professor and Head
Department of ECE
Vidya Academy of Science & Technology

Editor's Message

It gives me great pleasure to present the sixth edition of *Wissen 6.0*, the official magazine of the Department of Electronics and Communication Engineering. This edition reflects the creativity, technical insight, and enthusiasm of our students and faculty, highlighting their commitment to learning, innovation, and excellence.

Wissen 6.0 serves as a platform to share ideas, showcase emerging technologies, and encourage intellectual curiosity in the ever-evolving field of Electronics and Communication Engineering. Each contribution has been thoughtfully curated to ensure meaningful and engaging content for our readers.

I express my sincere gratitude to the Head of the Department, faculty members, and college management for their constant support and guidance throughout the preparation of this magazine. I also appreciate the dedicated efforts of the student contributors, designers, and coordinators whose hard work and cooperation made this publication possible.

I hope this edition of *Wissen 6.0* inspires curiosity, fosters innovation, and motivates readers to explore new horizons in technology.

Happy reading!

Warm regards,

Remya K R
Department of ECE
Vidya Academy of Science & Technology

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ARTIFICIAL INTELLIGENCE & MACHINE LEARNING

ADVANCES IN MACHINE LEARNING AND IoT FOR WATER QUALITY MONITORING

Alen.M.A
Student, S8 ECE A.Tech (2022–26)
Department of Electronics & Communication Engineering
Vidya Academy of Science and Technology
P.O. Thalakkottukara, Kerala, India

Abstract

Water quality monitoring is essential for protecting public health, ecosystems, and sustainable development. Traditional monitoring approaches are often limited by high cost, low spatial coverage, and delayed data acquisition. Recent advancements in the Internet of Things (IoT) and Machine Learning (ML) have enabled real-time, scalable, and intelligent monitoring of water quality parameters. IoT-based sensor networks allow continuous acquisition of physicochemical parameters such as pH, turbidity, dissolved oxygen, and temperature, while machine learning techniques provide predictive analytics and anomaly detection. This paper presents a comprehensive overview of recent developments in IoT-enabled water quality monitoring systems, emphasizing the role of machine learning in data analysis, prediction, and decision-making. The challenges, applications, and future research directions of smart water quality monitoring systems are also discussed.

I. Introduction

Water is one of the most essential natural resources for human survival, economic development, and ecological balance. However, rapid industrialization, urbanization, and climate change have significantly degraded water quality worldwide. Traditional water quality monitoring methods rely on manual sampling and laboratory analysis, which are time-consuming, costly, and unable to provide real-time insights.

Recent advancements in the Internet of Things (IoT) and Machine Learning (ML) have transformed conventional monitoring systems into intelligent and autonomous platforms. IoT enables continuous sensing and real-time data transmission, while ML facilitates data-driven decision-making by identifying patterns, trends, and anomalies in large datasets. Together, these technologies enable efficient, scalable, and predictive water quality management.

II. IoT-Based Water Quality Monitoring

IoT-based water quality monitoring systems consist of sensor nodes, communication networks, cloud platforms, and data analytics modules. Sensors are deployed to measure parameters such as pH, temperature, turbidity, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS).

A. *Wireless Communication Technologies*

Various wireless communication technologies are used for transmitting sensor data:

- **Short-Range Technologies:** Bluetooth, Zigbee, and Wi-Fi are used for localized monitoring due to low power consumption and ease of deployment.
- **Long-Range Technologies:** LoRa, NB-IoT, Sigfox, and cellular networks (4G/5G) enable long-distance data transmission for large-scale monitoring.

These technologies allow real-time data access, remote monitoring, and reduced operational costs compared to traditional methods.

Fig. 1: loT wireless technologies range and bandwidth,

III. Machine Learning Techniques for Water Quality Analysis

Machine learning plays a vital role in extracting meaningful insights from large-scale water quality data. ML algorithms enable prediction, classification, anomaly detection, and pattern recognition.

A. *Supervised Learning*

Supervised learning algorithms such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest (RF), and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) are widely used for predicting water quality indices and pollutant concentrations. These models learn from labeled datasets and provide high prediction accuracy for parameters such as pH, DO, BOD, COD, and turbidity.

B. *Unsupervised Learning*

Unsupervised learning techniques, including k-means clustering and Principal Component Analysis (PCA), are used to identify hidden patterns and classify water quality zones. These methods are particularly useful for anomaly detection and dimensionality reduction in large datasets.

C. *Hybrid and Deep Learning Models*

Hybrid models combining ML and deep learning approaches have shown superior performance in complex environments. Deep learning models such as CNNs and LSTMs are increasingly used for time-series prediction and spatiotemporal water quality analysis.

Fig. 2: Different types of machine learning.

IV. Applications

IoT and ML-based water quality monitoring systems are widely applied in:

- Drinking water supply monitoring
- River and lake pollution detection
- Industrial wastewater management
- Smart agriculture and aquaculture
- Urban water distribution networks

These systems enable early detection of contamination, improve decision-making, and enhance sustainability.

V. Challenges

Despite their advantages, several challenges remain:

- High deployment and maintenance costs
- Sensor calibration and reliability issues
- Data security and privacy concerns
- Energy constraints in remote deployments
- Integration complexity across heterogeneous systems

Addressing these challenges is essential for large-scale implementation.

VI. Future Prospects

Future research should focus on energy-efficient sensing, edge computing, federated learning, and AI-driven decision support systems. Integration of blockchain for secure data sharing and the use of digital twins for predictive water management are promising research directions.

VII. Conclusion

The integration of IoT and machine learning has significantly enhanced water quality monitoring by enabling real-time data acquisition, intelligent analysis, and predictive decision-making. These technologies offer scalable and cost-effective solutions for sustainable water resource management. Continued advancements in sensing, communication, and AI will further strengthen smart water monitoring systems and contribute to global water security.

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GENERATIVE AI IN ASSISTIVE TECHNOLOGIES

Krishna A T
Student, S8 ECE B.Tech. (2022–26)
Vidya Academy of Science and Technology
Department of Electronics & Communication Engineering
Thrissur, Kerala, India

Abstract

Generative Artificial Intelligence (AI) has rapidly evolved as a powerful paradigm capable of producing human-like text, images, audio, and other forms of synthetic data. Unlike traditional AI systems that focus on recognition or prediction, generative AI emphasizes content creation, enabling adaptive and intelligent interactions. Its integration into assistive technologies has created significant opportunities in healthcare, caregiving, accessibility, and daily-life support systems. Generative AI enhances personalization, improves decision-making efficiency, and supports inclusive human–machine interaction. These benefits are particularly valuable for individuals with disabilities, elderly populations, caregivers, and medical professionals. However, challenges such as algorithmic bias, lack of model transparency, privacy risks, and the generation of misleading information remain major concerns. This paper presents a detailed overview of generative AI in assistive technologies, discusses key application domains, identifies existing challenges, and outlines future research directions.

Introduction

Generative AI refers to a class of artificial intelligence models that learn the underlying patterns of data and generate new samples that closely resemble real-world data. Prominent examples include Large Language Models (LLMs), Generative Adversarial Networks (GANs), and diffusion-based models. Recent advancements in deep learning, computing power, and large-scale datasets have significantly improved the quality and reliability of generative AI outputs [1], [2].

Unlike conventional AI systems that are limited to classification or regression tasks, generative AI systems can create meaningful content such as natural language responses, images, and synthetic signals. This capability makes generative AI particularly suitable for assistive technologies, where flexible, adaptive, and human-centered interaction is essential.

Assistive technologies are designed to support individuals who face physical, sensory, cognitive, or age-related challenges. The incorporation of generative AI into these systems has enabled intelligent virtual assistants, socially assistive robots, personalized healthcare solutions, and adaptive learning tools. By offering real-time feedback and contextual understanding, generative AI enhances both usability and effectiveness of assistive systems [3].

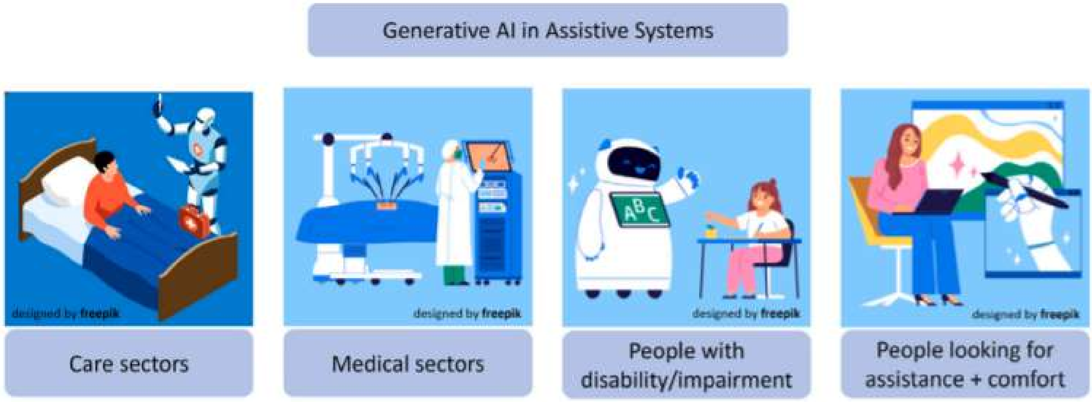

Fig. 1: Overview of generative AI applications in assistive systems, including care sectors, medical sectors, support for people with disabilities, and assistance for comfort [1]

Application Domains of Generative AI in Assistive Technologies

Generative AI has been applied across multiple assistive domains to enhance system intelligence, autonomy, and user experience:

- **Care Sectors:** In elderly care and home assistance, generative AI-powered robots and virtual companions provide daily reminders, emotional support, and social interaction. These systems help reduce loneliness, monitor health conditions, and assist caregivers by automating routine tasks [4].
- **Medical Sectors:** Generative AI supports healthcare professionals by assisting in medical documentation, diagnostic analysis, and clinical decision support. Language models help summarize patient records, while generative vision models assist in medical imaging and anomaly detection, improving diagnostic accuracy and efficiency.
- **People with Disabilities:** Generative AI enables personalized assistive solutions such as speech-to-text systems, emotion-aware conversational agents, and adaptive learning tools. These systems support individuals with visual, auditory, cognitive, or motor impairments by tailoring assistance according to individual needs [3].
- **People Seeking Assistance and Comfort:** AI-based companions provide mental health support, productivity assistance, and collaborative co-working environments. These systems act as conversational partners, offering emotional comfort and enhancing user engagement.

Challenges and Limitations

Despite its promising potential, the adoption of generative AI in assistive technologies is constrained by several challenges. Bias in training datasets can lead to unfair or discriminatory outputs, particularly affecting vulnerable user groups [5]. Another major issue is the lack of transparency and explainability in deep generative models, which reduces trust in safety-critical applications such as healthcare.

Generative AI systems are also prone to hallucinations, where models generate plausible but incorrect information. In assistive contexts, such errors may lead to misinformation or harmful decisions. Furthermore, the collection and processing of sensitive personal data raise significant privacy and ethical concerns. Addressing these issues is essential to ensure the safe and responsible deployment of generative AI-based assistive systems.

Future Scope and Conclusion

Future research in generative AI for assistive technologies should focus on improving model explainability, fairness, and robustness. Techniques such as hybrid AI models, human-in-the-loop systems, and transparent decision-making frameworks can enhance trust and reliability. Additionally, establishing standardized evaluation metrics and ethical guidelines will be critical for large-scale deployment.

In conclusion, generative AI has the potential to significantly transform assistive technologies by enabling intelligent, adaptive, and human-centered solutions. When developed responsibly, generative AI can improve accessibility, enhance healthcare delivery, and elevate overall quality of life for diverse user populations.

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COMPARATIVE ANALYSIS OF MACHINE LEARNING ALGORITHMS FOR ANTENNA ALIGNMENTS

Adwaith K
Student, S8 ECE B.Tech (2022-26)
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

Antenna alignment plays a crucial role in ensuring reliable and efficient wireless communication. Even small deviations in antenna spacing or orientation can significantly degrade system performance. Conventional antenna alignment techniques rely on manual adjustments or expensive optical and robotic systems, which are often time consuming and difficult to scale. This paper presents a machine learning based approach for antenna alignment prediction using only scattering parameters (S-parameters). Three models:Multilayer Perceptron (MLP), Convolutional Neural Network (CNN), and Long Short Term Memory (LSTM) are evaluated for predicting antenna distance and angular orientation. Experimental data collected from LTCC based antennas using a Vector Network Analyzer is used for training and testing. The results demonstrate that MLP and LSTM achieve up to 97% accuracy in distance prediction, while CNN achieves 86% accuracy in angular prediction. The proposed approach offers a low cost, scalable, and automated solution suitable for future 5G and IoT systems.

Introduction

With the rapid growth of modern wireless communication systems such as 5G, Internet of Things (IoT), and satellite networks, accurate antenna alignment has become increasingly important. Improper alignment leads to reduced signal strength, increased interference, and degraded communication quality. Traditional alignment techniques are often manual, labor-intensive, or dependent on costly hardware systems.

Recent advancements in machine learning (ML) have enabled intelligent data driven solutions in the physical layer of wireless communication. Scattering parameters (S-parameters), widely used to characterize RF systems, contain valuable information about antenna behavior. By analyzing these parameters using ML models,antenna alignment can be predicted without additional sensors or hardware. This work explores the feasibility of using ML techniques to automate antenna alignment using S-parameter measurements alone.

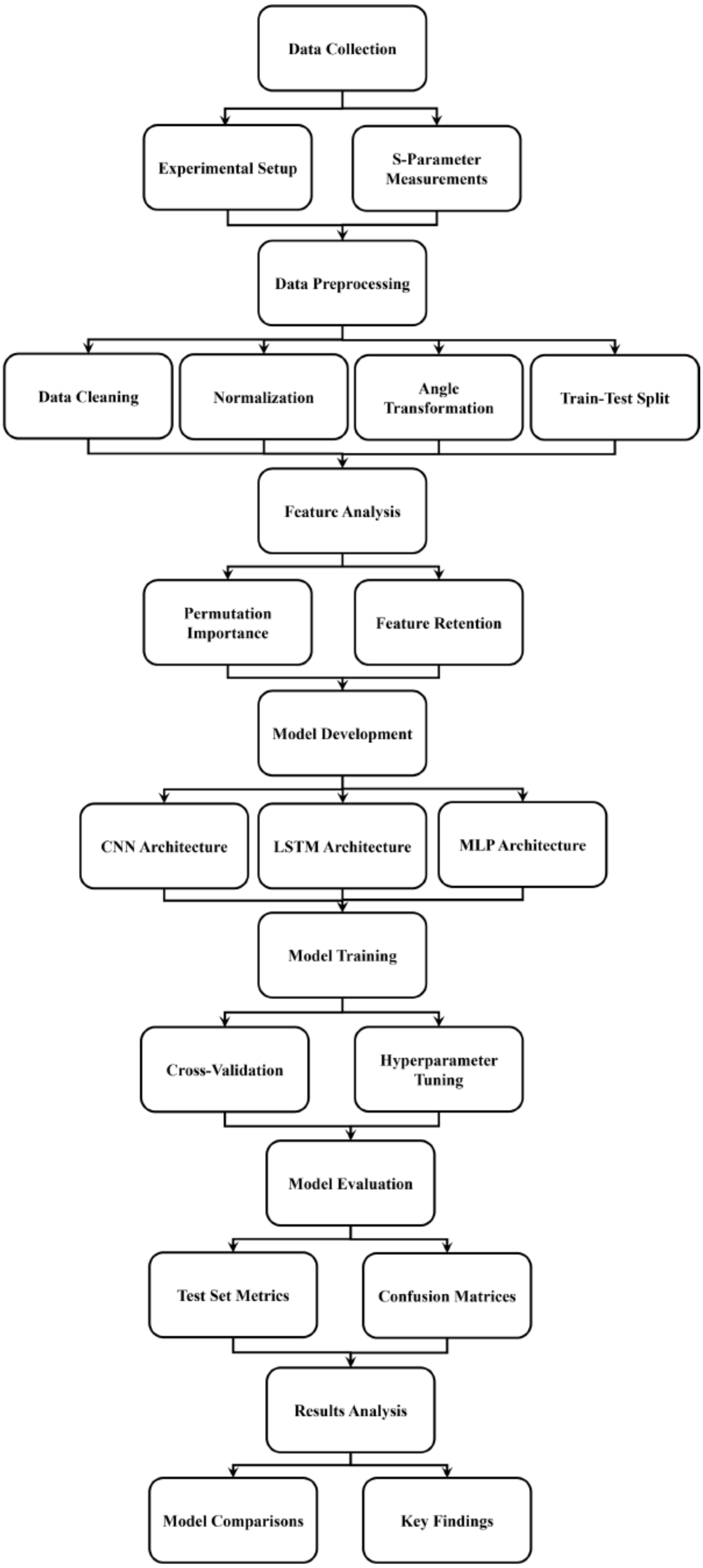

Fig. 1: Methodology Block Diagram for Antenna Alignment Prediction[1]

Experimental Setup and Data Collection

Two identical Low Temperature Co-fired Ceramic (LTCC) antennas resonating at 2.32 GHz were used in the experimental setup. The antennas were connected to a calibrated Vector Network Analyzer (VNA) to measure reflection and transmission coefficients (S11, S22, S21, and S12).

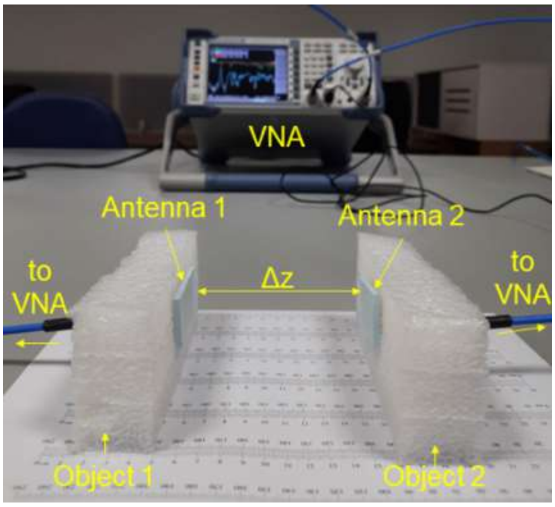

Fig. 2: Experimenmtal setup for gap alignment measurements[1]

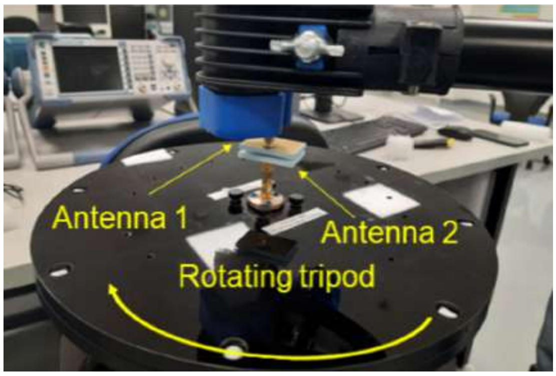

Fig. 3: Experimental setup for angular alignment measurements[1]

- **Gap Alignment Measurements:** For distance prediction, the antennas were placed facing each other with separation distances of 0 mm, 2 mm, 13 mm, and 150 mm. These distances cover both near field and far field regions, allowing the dataset to capture different electromagnetic coupling behaviors.
- **Angular Alignment Measurements:** For angular prediction, the separation distance was fixed, and one antenna was rotated from 0° to 360° in steps of 30°. At each orientation, S-parameters were recorded over a frequency range of 2–3.01 GHz.

A total of 4,001 samples were collected, forming a comprehensive dataset for machine learning analysis.

Data Preprocessing and Feature Analysis

Before training the models, the collected data was preprocessed to improve learning efficiency. Frequency values were normalized to avoid scale dominance, and angular values were transformed into sine and cosine components to preserve circular continuity.

Feature importance analysis using permutation techniques revealed that transmission coefficients (S21 and S12) are dominant indicators for distance prediction, while reflection coefficients (S11 and S22) play a key role in angular prediction. These findings align well with electromagnetic theory, validating the physical relevance of the selected features.

Machine Learning Models

Three different machine learning architectures were implemented and compared:

- **Multilayer Perceptron (MLP):** A deep feedforward neural network capable of modeling complex nonlinear relationships between S-parameters and antenna alignment.
- **Convolutional Neural Network (CNN):** Utilized to capture spatial patterns in frequency-dependent S-parameter data, making it particularly effective for angular prediction.

- **Long Short-Term Memory (LSTM):** A recurrent neural network designed to capture correlated dependencies among S-parameters, showing strong performance in distinguishing small distance variations.

All models were trained using categorical cross-entropy loss and evaluated using accuracy, precision, recall, and F1-score metrics.

Results and Discussion

The performance comparison revealed clear strengths for each model:

- **Distance Prediction:** MLP and LSTM achieved the highest accuracy of 97%, with LSTM showing superior capability in distinguishing closely spaced distances such as 0 mm and 2 mm.
- **Angular Prediction:** CNN outperformed the other models with an accuracy of 86%, owing to its ability to extract spatial features from S-parameter variations.

Most misclassifications occurred in physically ambiguous cases, such as small distance gaps and angular boundary values (0° and 360°), where S-parameter responses are inherently similar.

Applications

The proposed ML-based antenna alignment technique has wide-ranging applications:

- Automated antenna alignment in 5G and 6G base stations
- Smart IoT and wireless sensor networks
- Satellite and aerospace communication systems
- Low-cost RF testing and calibration setups

Future Scope and Conclusion

This study demonstrates that machine learning models can effectively predict antenna alignment using only S-parameter data, eliminating the need for expensive alignment hardware. The results confirm that different ML architectures excel at different alignment tasks, with MLP and LSTM suited for distance prediction and CNN for angular prediction.

Future work may focus on real time implementation, hybrid ML models, larger datasets, and integration with adaptive antenna systems. With further advancements, ML-based antenna alignment can become a key component of intelligent and automated wireless communication infrastructures.

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APPLICATION OF MACHINE LEARNING-ASSISTED GLOBAL OPTIMIZATION FOR IMPROVEMENT IN DESIGN AND PERFORMANCE OF OPEN RESONANT CAVITY ANTENNA

Alwin K Sunny
Student, S8 ECE B.Tech (2022–26)
Department of Electronics & Communication Engineering,
Vidya Academy of Science and Technology,
Thrissur, Kerala, India

ABSTRACT

Open resonant cavity antennas (ORCA) exhibit strong potential for compact, high-gain broadband communication. Conventional EM-based manual tuning becomes inefficient under multi-parameter coupling [2]. This work applies ML-assisted global optimization using PSADEA to enhance broadside gain, impedance bandwidth, and sidelobe suppression realistically. The optimized design achieved 19.1% bandwidth, 17.5 dBi gain, and –15.6 dB SLL, verified experimentally [1]. The results validate AI-driven cavity contour discovery for simultaneous radiation improvement under practical constraints.

I. INTRODUCTION

Open Resonant Cavity Antennas (ORCA) have emerged as an efficient class of high-gain radiators capable of achieving strong broadside radiation without the need for bulky reflectors [1]. The radiation mechanism of ORCA is based on the formation of standing-wave resonance within a partially open cavity, where constructive interference between multiple reflections produces directive radiation. Compared to conventional reflector antennas, ORCA structures offer reduced profile, compactness, and ease of integration with planar feeding techniques [2].

However, the performance of ORCA is highly sensitive to multiple geometrical and electromagnetic parameters, including cavity height, sidewall inclination, feed position, dielectric properties, and superstrate reflection characteristics. These parameters are strongly interdependent, leading to a complex, nonlinear, and multimodal design space. Traditional design approaches rely heavily on full-wave electromagnetic (EM) simulations combined with manual or parametric tuning, which is computationally expensive and often fails to achieve global optimality [2]. As the number of design variables increases, the optimization problem becomes increasingly challenging due to the curse of dimensionality and strong parameter coupling.

To address these challenges, evolutionary optimization techniques such as Genetic Algorithms (GA) and Differential Evolution (DE) have been widely applied in electromagnetic design problems [3], [4]. These algorithms enable global search capability and can escape local optima; however, they require a large number of EM simulations, making them time-consuming when applied directly to complex antenna structures.

Recent advancements in Machine Learning (ML) have introduced surrogate-assisted optimization as a powerful alternative for accelerating antenna design [5]. In this approach, surrogate models such as

Gaussian Process Regression (GPR), Artificial Neural Networks (ANN), or Random Forests (RF) are trained using a limited set of EM simulation data to approximate antenna performance metrics such as gain, reflection coefficient (S11), and sidelobe level (SLL). These models significantly reduce computational cost by replacing expensive EM evaluations with fast predictive approximations.

In this work, a Machine Learning-assisted global optimization framework based on PSADEA (Pre-Screening Assisted Differential Evolution Algorithm) is employed to enhance the performance of ORCA. The proposed approach integrates surrogate modeling with a self-adaptive Differential Evolution optimizer, enabling efficient exploration of the design space while maintaining physical feasibility [1]. The algorithm utilizes a Lower Confidence Bound (LCB) acquisition strategy to balance exploration and exploitation, ensuring that only promising candidate designs are selected for full-wave EM validation.

The results demonstrate that ML-assisted optimization can significantly improve impedance bandwidth, gain, and sidelobe suppression simultaneously, which is difficult to achieve using conventional design techniques. This highlights the potential of AI-driven methodologies in advancing next-generation antenna design, particularly for applications in high-frequency communication, radar systems, and emerging 5G/6G technologies.

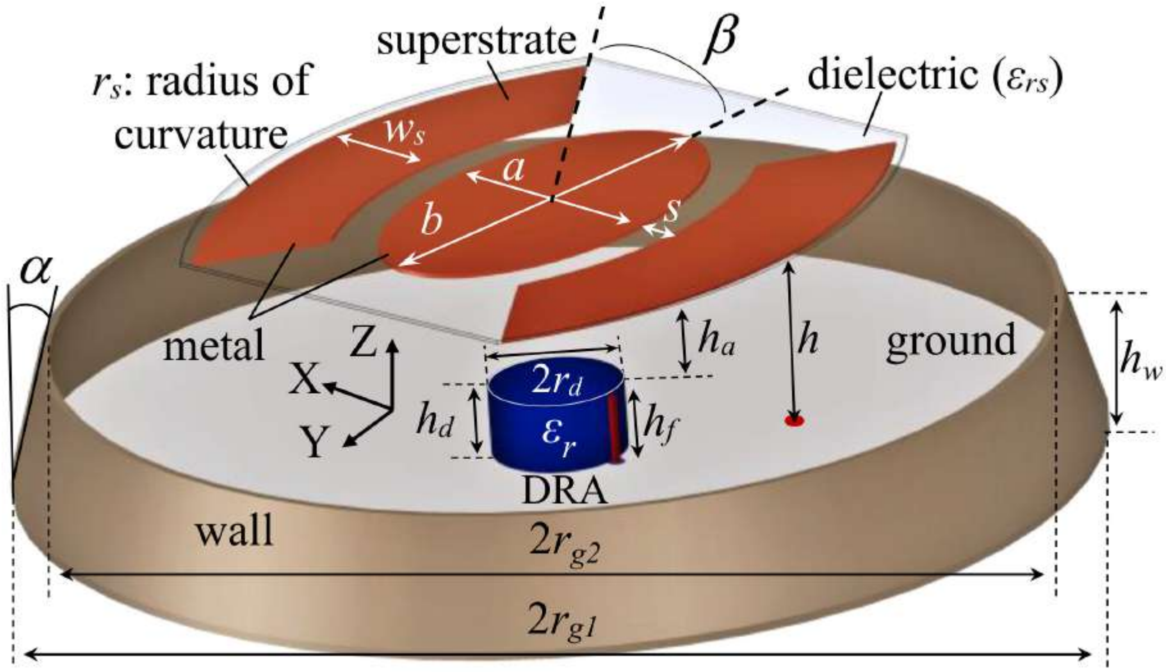

Fig. 1: 3D structure of the Open Resonant Cavity Antenna (ORCA) showing cavity, ground plane, dielectric feed, and superstrate.[1]

II. Key Components of ML-Assisted ORCA Optimization

ML-assisted ORCA synthesis consists of three computational and physical validation layers. First, surrogate regression learners are trained on EM parametric sweeps to approximate gain, S11, and SLL without repeated simulations. Gaussian-Process (GP) regression is highly suitable because it predicts both performance and uncertainty [5].

Second, PSADEA employs a self-adaptive Differential Evolution engine where mutation factor (F) and crossover probability (CR) evolve dynamically, ensuring realistic geometry mutations [3].

Third, the lower-confidence-bound (LCB) acquisition criterion pre-screens candidates so that only promising designs are evaluated using full-wave EM solvers.

Finally, Geometrical Optics (GO) interpretation validates energy confinement and radiation trends, linking AI-generated designs to classical EM theory [2].

III. Results and Discussions

The performance of the PSADEA-optimized ORCA was evaluated through both full-wave electromagnetic simulations and experimental measurements to validate impedance and radiation characteristics. Figure 1 illustrates the simulated and measured reflection coefficient (S11), where a close agreement is observed between the two responses. This confirms the accuracy of the surrogate-assisted optimization and the reliability of the fabricated prototype. The antenna achieves a wide impedance bandwidth spanning approximately 3.57–4.3 GHz (about 18.5%), which is a significant improvement over conventional cavity antenna designs [1].

The enhanced bandwidth can be attributed to the optimized cavity contour and improved impedance matching at the feed location. The ML-assisted optimization effectively identifies geometrical configurations that minimize reflection losses across a broader frequency range. Unlike traditional trial-and-error approaches, the surrogate-based framework efficiently explores the design space and converges toward high-performance solutions with reduced computational cost [5].

Radiation characteristics of the optimized ORCA were analyzed at the center frequency of 3.7 GHz. The measured E-plane and H-plane radiation patterns (Figures 2 and 3) demonstrate strong broadside radiation with high directivity. The antenna achieves a peak gain of approximately 17.5 dBi, indicating efficient confinement and constructive interference of electromagnetic energy within the cavity [1]. The stability of the main lobe across the operating band confirms that the antenna maintains consistent radiation performance under broadband conditions.

A key improvement observed in the optimized design is the significant reduction in sidelobe levels (SLL), reaching approximately –15.6 dB. This reduction is critical for minimizing unwanted radiation in off-axis directions, thereby improving signal quality and reducing interference. The sidelobe suppression is achieved through careful reshaping of the cavity geometry, which controls field leakage and phase distribution at the aperture. Such simultaneous optimization of gain, bandwidth, and SLL is difficult to achieve using conventional design methods due to strong parameter coupling [2].

Additionally, the polarization characteristics show a clear distinction between co-polarized and cross-polarized components, with low cross-polarization levels indicating good radiation purity. This is essential for practical communication systems where polarization mismatch can lead to power loss.

The effectiveness of the PSADEA algorithm lies in its ability to balance global exploration and local exploitation. By integrating surrogate modeling with evolutionary optimization, the algorithm reduces the number of expensive EM simulations while still achieving near-global optimal solutions [3]. The lower confidence bound (LCB) criterion ensures that only promising candidate designs are evaluated, improving overall optimization efficiency.

Minor discrepancies between simulated and measured results can be attributed to fabrication tolerances, connector losses, and material property variations. However, these deviations remain within acceptable limits, validating the robustness of the ML-assisted design methodology.

Overall, the results demonstrate that the proposed ML-assisted optimization framework significantly enhances ORCA performance in terms of bandwidth, gain, and sidelobe suppression. This confirms the potential of combining machine learning with electromagnetic simulation for advanced antenna design, especially in complex multi-parameter optimization scenarios.

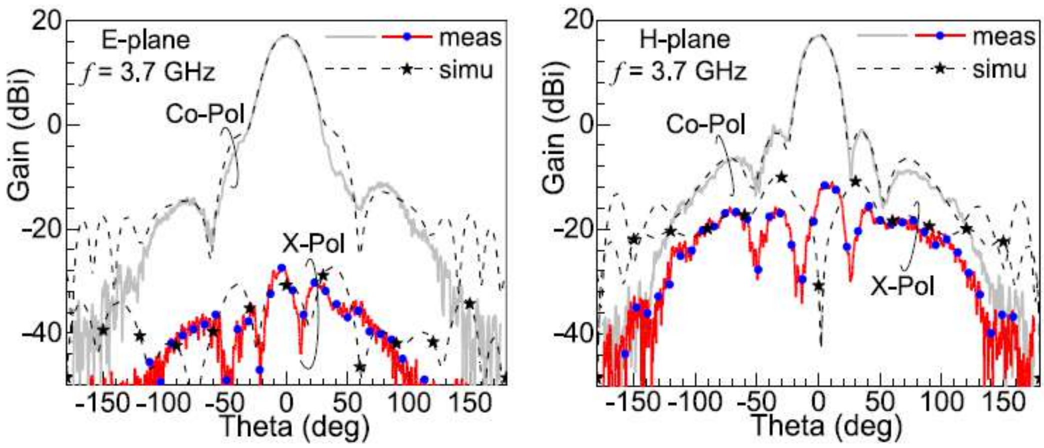

Fig. 2: Measured E-plane radiation pattern of optimized ORCA at 3.7 GHz showing Co-Pol and X-Pol characteristics.[1]

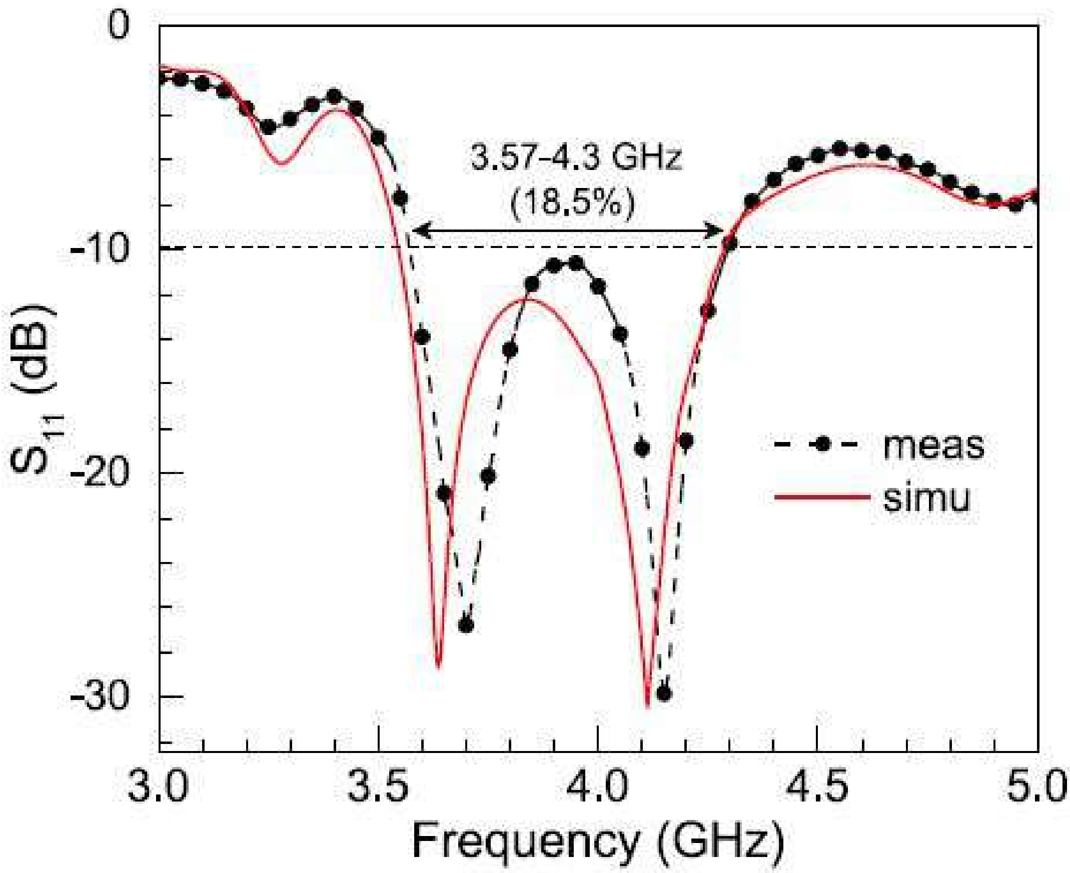

Fig. 3: Simulated vs measured S11 of the optimized ORCA showing wide impedance bandwidth.[1]

IV. Applications of ML-Optimized ORCA Design

ML-optimized ORCA architectures enable compact, high-gain radiators suitable for next-generation communication systems. High directivity antennas are widely used in wireless communication, radar, and satellite systems [2]. Improved sidelobe suppression enhances interference mitigation and detection performance.

V. Challenges in ML-Assisted ORCA Optimization

ML-assisted ORCA synthesis faces challenges such as high initial EM dataset cost and surrogate model reliability. Surrogate-based optimization requires high-quality training data to ensure accuracy [5]. Fabrication tolerances and environmental sensitivity also affect practical implementation.

VI. Future Prospects and Conclusion

ML-assisted optimization is emerging as a powerful paradigm in antenna design [4]. Future work includes integration with EM solvers such as CST and HFSS for automated design pipelines. Advanced ML models like deep neural networks and physics-informed learning can further enhance prediction accuracy and reduce simulation cost.

In conclusion, ML-assisted global optimization enables efficient exploration of complex antenna design spaces. The ORCA results demonstrate significant improvements in bandwidth, gain, and sidelobe suppression, validating the effectiveness of AI-driven antenna synthesis.

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Neuromorphic Computing: Brain-Inspired Chips for the Future of AI

Vyshnav P
Student, S8 ECE B.Tech (2022–26)
Department of Electronics & Communication Engineering
Vidya Academy of Science and Technology
P.O. Thalakkottukara, Kerala, India

Abstract

Traditional computing architectures face significant limitations in power consumption and processing efficiency, especially for artificial intelligence tasks. Neuromorphic computing, inspired by the human brain's structure, offers a revolutionary approach using artificial neurons and synapses to process information in a parallel, event-driven manner. This paper explores the fundamental principles of neuromorphic computing, current implementations like Intel Loihi and IBM TrueNorth, applications in robotics and edge AI, and the technology's role in shaping the future of computation.

I Introduction

The digital age has witnessed exponential growth in data processing demands. Traditional von Neumann architecture systems, where processing and memory are separated, face significant bottlenecks in speed and energy efficiency, particularly for AI and machine learning applications requiring massive parallel computations.

The human brain operates fundamentally differently. With approximately 86 billion neurons and trillions of synapses, it processes information in a massively parallel, energy-efficient manner, consuming only about 20 watts. This remarkable efficiency has inspired neuromorphic computing systems that mimic the brain's architecture.

Neuromorphic computing represents a paradigm shift from traditional computing. Instead of sequential instruction execution, neuromorphic chips use artificial neurons and synapses for parallel, event-driven processing. This enables real-time learning, adaptation, and ultra-low power consumption—ideal for edge computing, robotics, and AI applications where power and latency are critical.

II Overview of Neuromorphic Computing

Neuromorphic computing mimics biological neural networks. Unlike traditional processors using clock-driven synchronous operations, neuromorphic chips operate asynchronously, processing information only when events occur. This spike-based computing approach significantly reduces power consumption.

The fundamental building blocks are:

- **Artificial Neurons** – Processing units that generate output spikes when thresholds are reached.
- **Artificial Synapses** – Connections storing weights that can be modified through learning.
- **Spiking Neural Networks (SNNs)** – Networks that communicate through discrete spike events encoding information in timing and frequency.

Current Implementations:

Intel's Loihi 2 contains about 130,000 neurons and 130 million synapses with on-chip learning capabilities. IBM's TrueNorth has 1 million neurons and 256 million synapses while consuming just 70 milliwatts. Europe's BrainScaleS operates 10,000 times faster than biological real-time, while the University of Manchester's SpiNNaker uses ARM processors arranged in a neuromorphic architecture.

III Advantages of Neuromorphic Computing

- **Ultra-Low Power Consumption** Event-driven processing achieves 100–1000x energy efficiency improvements compared to conventional processors.
- **Real-Time Processing** Parallel architecture enables real-time sensory data processing without traditional latency.
- **Adaptive Learning** Continuous on-chip learning allows deployed systems to adapt without external processing.
- **Fault Tolerance** Distributed neural structures provide resilience to component failures.
- **Scalability** Adding neurons and synapses avoids memory bottlenecks typical of von Neumann architectures.

IV Applications and Use Cases

- **Robotics and Autonomous Systems** Real-time sensory processing enables navigation and obstacle avoidance.
- **Edge AI and IoT** Energy-efficient inference for smart sensors, wearable devices, and industrial monitoring.
- **Computer Vision** Event-based cameras enable high-speed visual processing for surveillance and autonomous vehicles.
- **Pattern Recognition** Applications include speech recognition, gesture detection, and anomaly detection.
- **Optimization** Useful for logistics, resource allocation, and routing problems.

V Current Developments and Challenges

Neuromorphic research is advancing rapidly. Indian institutions such as IIT Bombay, IIT Madras, and IISc are actively researching neuromorphic systems. Government initiatives in semiconductors and AI create new opportunities for development and adoption.

Recent innovations include memristor integration and photonic neuromorphic computing using light for faster computation.

However, several challenges remain:

- Programming complexity due to limited frameworks
- Lack of algorithms for spiking neural networks
- Manufacturing difficulties integrating new devices with CMOS technology
- Benchmarking challenges between traditional and neuromorphic systems
- Limited commercial availability of neuromorphic hardware

VI Future Scope and Conclusion

Neuromorphic computing has strong potential as limitations of traditional architectures become increasingly apparent. Future developments may include neuromorphic chips in consumer electronics, large-scale AI training systems, and hybrid processors combining traditional and neuromorphic architectures.

Neuromorphic computing represents a fundamental rethinking of computing inspired by nature. By emulating the human brain, these systems promise more efficient, adaptive, and intelligent machines.

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PREDICTING BOTH REMAINING USEFUL LIFE (RUL) AND CAPACITY FADE IN A UNIFIED MACHINE LEARNING MODEL

Albin Shajan C
Student, S8 ECE B.Tech (2022-26)
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

In the rapidly evolving field of energy storage, the reliability and longevity of lithium-ion batteries (LIBs) remain a central challenge. Traditional approaches for battery health monitoring and prognostics have treated Remaining Useful Life (RUL) and Capacity Fade as two separate analytical targets. However, disjointed methods fail to capture the intrinsic interdependence between the degradation rate of a battery's capacity and its remaining operational lifespan. Addressing this gap, this paper introduces a groundbreaking framework that simultaneously predicts both RUL and Capacity Fade in a unified machine learning (ML) model. By integrating dual-target learning into a hybrid ensemble of k-Nearest Neighbors (kNN), Random Forest (RF), and Extreme Gradient Boosting (XGBoost), the proposed system achieves high predictive accuracy. This unified approach represents a paradigm shift in battery health prognostics, enabling smarter maintenance strategies and real-time optimization in Battery Management Systems (BMS).

Introduction

In the domain of energy storage, particularly for electric vehicles (EVs) and renewable energy systems, the performance of lithium-ion batteries (LIBs) is critical. Traditional methods for prognostics have often treated Remaining Useful Life (RUL) and Capacity Fade as independent metrics. However, such methods fail to capture the intrinsic interdependence between capacity degradation and operational lifespan.

Recent research addresses this by proposing a unified machine learning model that predicts both targets simultaneously. Unlike traditional RUL models that only predict the number of remaining charge-discharge cycles before end-of-life (EOL), this dual-target model evaluates both the quantitative loss of capacity and the remaining life expectancy. This holistic framework allows for a comprehensive understanding of degradation patterns, essential for optimizing Battery Management Systems (BMS).

Proposed Methodology

The proposed system integrates dual-target learning into a hybrid ensemble of three powerful machine learning algorithms. Each contributes distinct strengths:

- **k-Nearest Neighbors (kNN):** Captures localized data patterns.
- **Random Forest (RF):** Excels at managing non-linear relationships and ranking feature importance.

- **Extreme Gradient Boosting (XGBoost):** Provides refined gradient-based optimization and noise resistance.

The hybrid ensemble combines these models through weighted averaging and ensemble techniques. A key novelty introduced is the **“Remaining Capacity Cycles” (RCC)**. This metric quantifies the number of effective cycles a battery can still perform while maintaining acceptable capacity levels, bridging the conceptual gap between RUL and Capacity Fade.

The dataset employed comprises multi-cycle charge and discharge data from multiple LIB cells, including parameters such as capacity, voltage, temperature, cycle index, and discharge duration. Advanced preprocessing—normalization, feature selection, and outlier removal—ensures data consistency.

Experimental Results

Through ensemble learning and meta-model refinement, the system achieves remarkably high predictive accuracy. The performance metrics for the dual-target approach are as follows:

- R^2 **Value:** 0.996457
- **RMSE:** 0.016861
- **MAE:** 0.008956

These results demonstrate the superior performance of the hybrid dual-target approach over conventional single-output prediction models. Beyond statistical accuracy, the model provides practical insights for predictive maintenance scheduling and safety assurance by enabling early detection of performance degradation.

Conclusion

The simultaneous dual-target prediction model establishes a new direction in predictive analytics for energy storage systems. By bridging the methodological divide between RUL and Capacity Fade prediction, and introducing the Remaining Capacity Cycles (RCC) metric, this framework enhances prediction precision and redefines the understanding of battery degradation as a unified process.

The fusion of hybrid machine learning with dual-target modeling marks a significant advancement toward more intelligent, efficient, and sustainable battery management solutions. Moreover, the model’s hybrid structure and feature scalability make it extendable to other electrochemical storage systems beyond LIBs, including solid-state and sodium-ion batteries.

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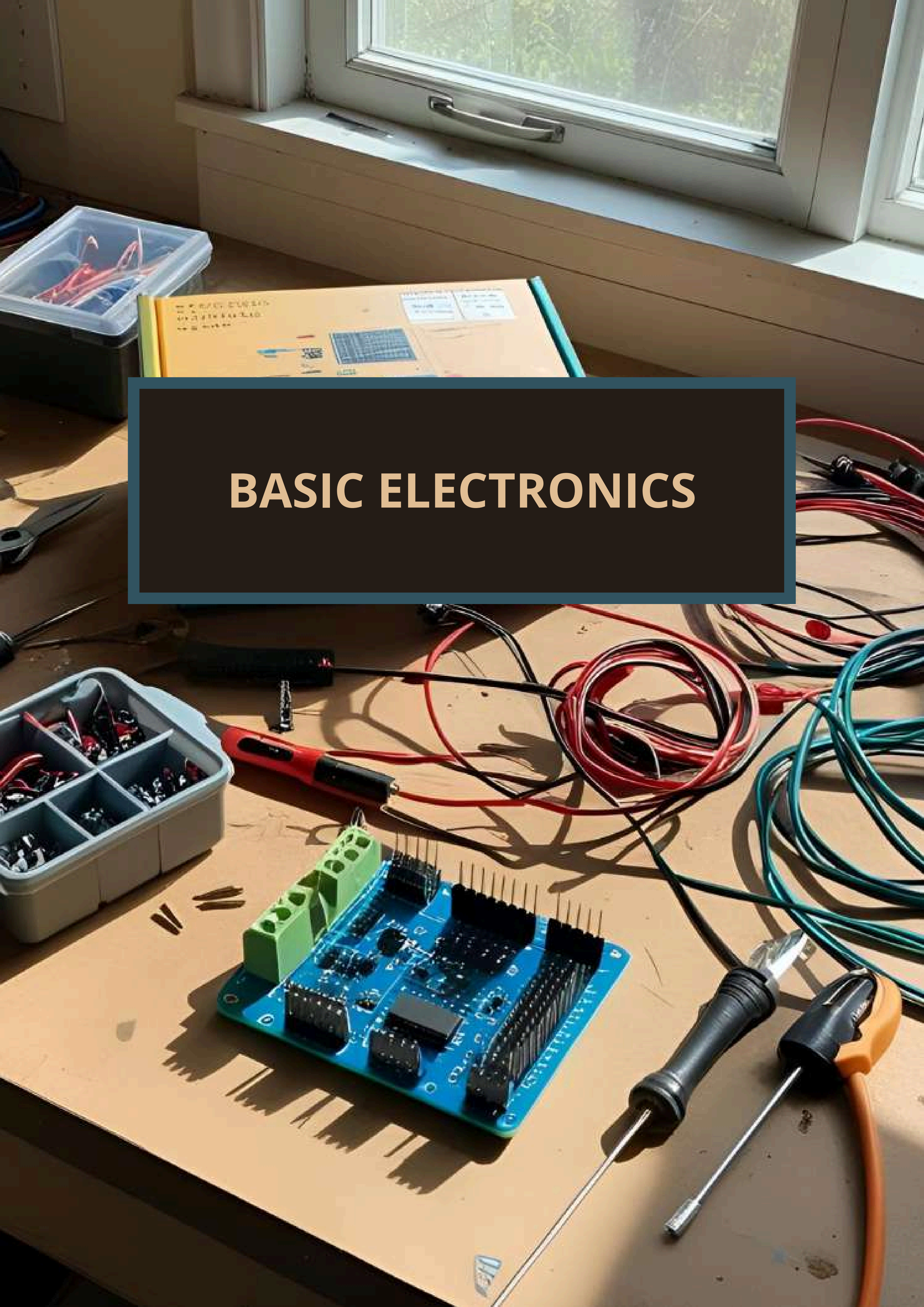
BASIC ELECTRONICS



QUANTUM DOTS : AN EMERGING TECHNOLOGY IN ELECTRONICS AND COMMUNICATION ENGINEERING

Gokul Nair
Student, S6 ECE B.Tech (2023–27)
Vidya Academy of Science and Technology
Department of Electronics and Communication Engineering
P.O. Thalakottukara, Kerala

Abstract

Emerging technologies are transforming the field of Electronics and Communication Engineering by enabling faster, smaller, and more efficient systems. Among these technologies, quantum dots have gained significant attention due to their unique electrical and optical properties. Quantum dots are nanoscale semiconductor particles that exhibit quantum mechanical behavior, making them highly suitable for advanced applications in displays, communication systems, medical imaging, and quantum computing. This article discusses the basic concept of quantum dots, their key characteristics, applications in ECE, associated challenges, and future prospects. In addition, the ability of quantum dots to be precisely controlled at the nanoscale opens new possibilities for developing compact and energy-efficient electronic devices. As research continues, quantum dots are expected to play a vital role in bridging theoretical quantum concepts with real-world engineering applications.

Introduction

Electronics and Communication Engineering is continuously evolving with the development of emerging technologies such as nanotechnology, quantum computing, and advanced semiconductor devices. These technologies aim to overcome the limitations of conventional electronic components in terms of size, efficiency, and performance.

Quantum dots represent one such breakthrough technology. Due to their extremely small size—typically in the range of 2 to 10 nanometers—quantum dots exhibit unique properties that differ from bulk semiconductor materials. Their ability to emit light of specific wavelengths makes them highly valuable in modern electronic and communication systems. With the rapid miniaturization of electronic components, traditional semiconductor technologies are approaching their physical limits. Quantum dot technology provides a promising alternative by exploiting quantum mechanical effects, enabling improved performance in terms of speed, efficiency, and functionality.

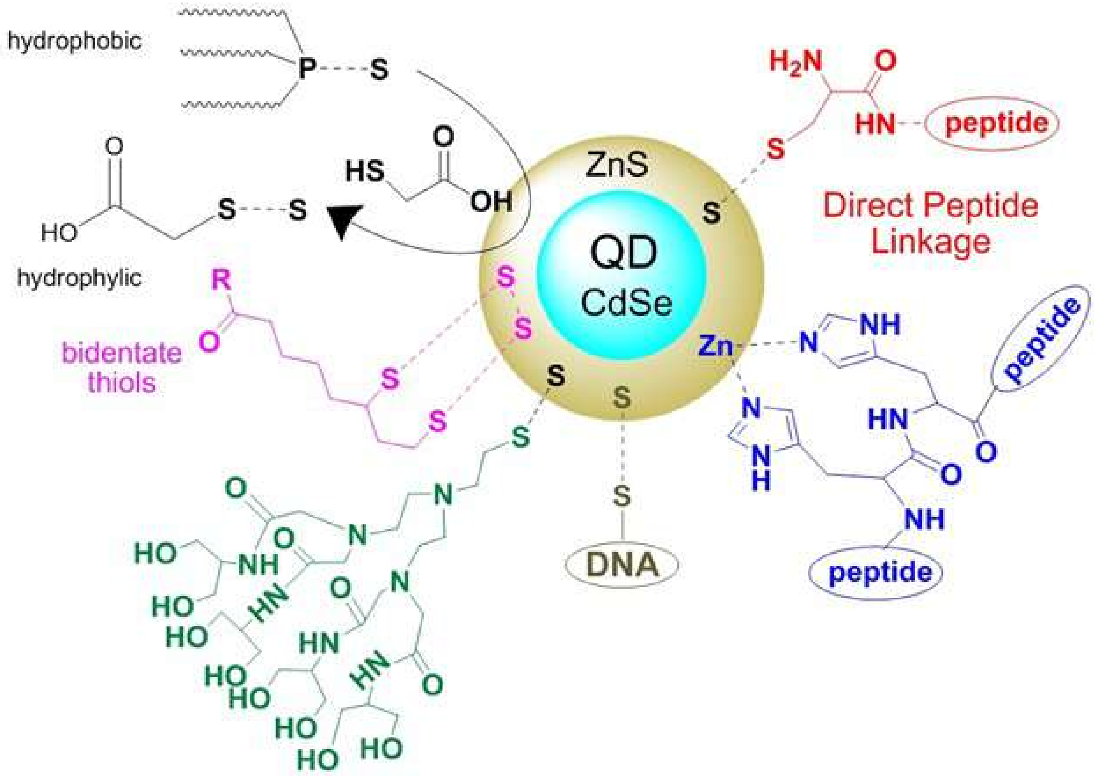


Fig. 1: Structure of a quantum dot ([1])

Key Components / Characteristics of Quantum Dots

Quantum dots are nanoscale semiconductor crystals composed of materials such as cadmium selenide (CdSe), cadmium sulfide (CdS), or indium phosphide (InP). Their key characteristics include:

- **Size-dependent properties:** The wavelength (color) of emitted light depends on the size of the quantum dot.
- **Core-shell structure:** A semiconductor core coated with another material to enhance stability and efficiency.
- **Quantum confinement effect:** Charge carriers are confined in all three dimensions, resulting in discrete energy levels.
- **High brightness and stability:** Quantum dots offer superior brightness and longer lifespan compared to traditional phosphors.

Advanced fabrication techniques such as colloidal synthesis and epitaxial growth enable precise control over the size and shape of quantum dots, which directly influences their electrical and optical behavior.

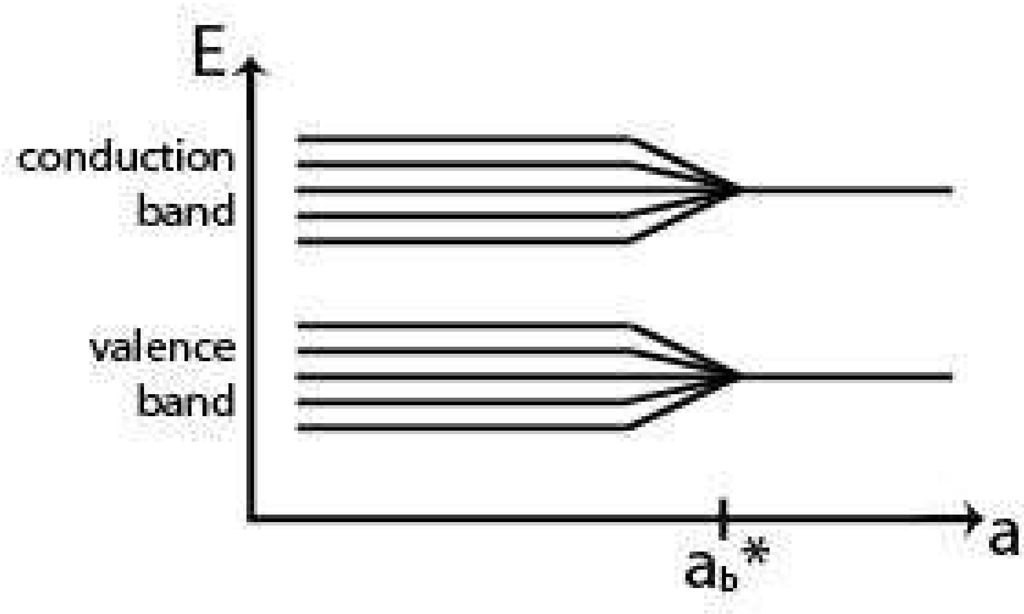


Fig. 2: Illustration of quantum confinement effect ([2])

Applications of Quantum Dots in ECE

Quantum dots have a wide range of applications in Electronics and Communication Engineering:

- **Display Technology:** Used in QLED displays for improved color accuracy, brightness, and energy efficiency.
- **Optical Communication:** Employed in lasers and photodetectors for high-speed optical communication systems.
- **Medical Imaging and Sensors:** Utilized in bio-imaging due to high sensitivity and precision.
- **Quantum Computing:** Investigated as potential qubits for secure and high-speed data processing.

Role of Quantum Dots in Communication Systems

Quantum dots play a significant role in optical and photonic communication systems. Their tunable emission wavelengths and high efficiency make them suitable for quantum dot lasers and optical amplifiers. These devices enable high-speed data transmission with reduced signal loss in fiber-optic networks. Quantum dot-based photodetectors also offer enhanced sensitivity, supporting next-generation communication technologies.

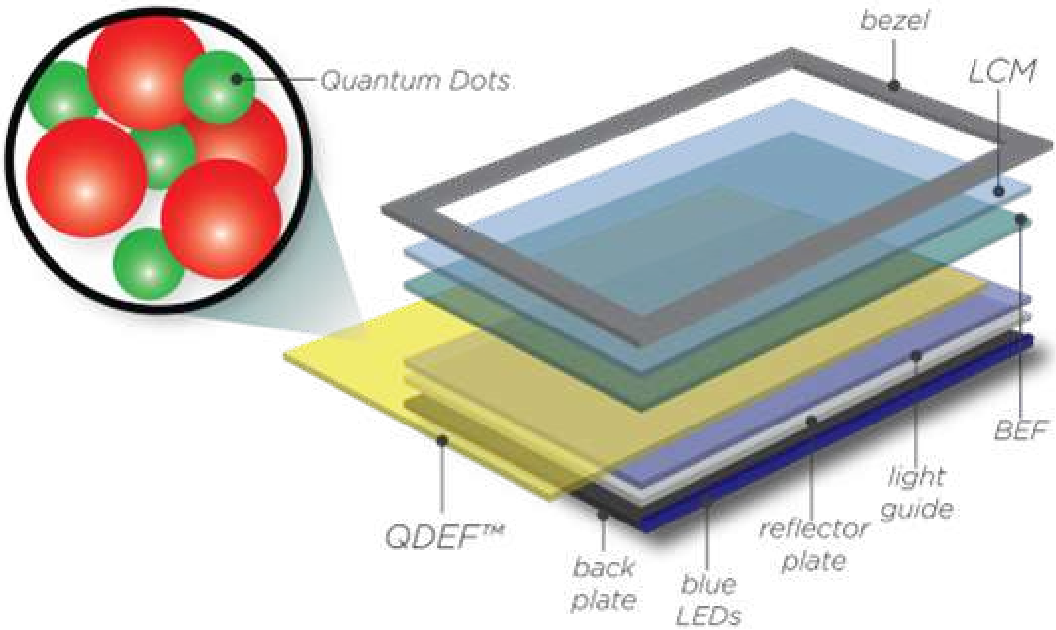


Fig. 3: Exploded diagram of quantum dot enhancement film (QDEF) in LCD displays ([3])

Recent Developments and Industry Adoption

Major companies such as Samsung and Nanosys have successfully implemented quantum dots in commercial display technologies like QLED televisions. Research is also focused on developing eco-friendly quantum dots that eliminate toxic materials while maintaining performance. Improvements in fabrication techniques are accelerating their adoption in communication systems, sensors, and quantum information processing.

Challenges

Despite their advantages, quantum dots face several challenges:

- Toxicity due to heavy metal content
- High manufacturing costs
- Stability issues under heat, light, and moisture
- Difficulty in large-scale production

Addressing these challenges requires interdisciplinary research in materials science, electronics, and environmental engineering.

Future Prospects and Conclusion

Quantum dots hold immense potential in shaping the future of Electronics and Communication Engineering. With advancements in nanotechnology and material science, quantum dots are expected to play a crucial role in next-generation communication systems, high-resolution displays, and quantum devices. Continued research and innovation will help overcome existing challenges and unlock their full potential.

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NANOTECH ELECTRONICS: BALANCING POWER AND PERFORMANCE

Anjana Sunil
Student, S6 ECE B.Tech (2023–27)
Vidya Academy of Science and Technology
Department of Electronics and Communication Engineering
P.O. Thalakottukara, Kerala

INTRODUCTION

In the era of ubiquitous computing, the demand for high-performance processing in mobile devices, electric vehicles, and AI data centers has reached an all-time high [4]. However, as transistors shrink toward the atomic scale, engineers face a "thermal wall" where increased performance leads to exponential rises in power leakage and heat dissipation [5]. This article examines the critical trade-offs between dynamic power, static leakage, and clock frequency. We explore modern solutions including FinFET/GAA architectures, Dynamic Voltage and Frequency Scaling (DVFS), and Wide Bandgap (WBG) semiconductors [6]. By analyzing the transition from monolithic designs to heterogeneous 3D integration, we demonstrate how architectural innovation can sustain performance gains while staying within strict thermal envelopes.

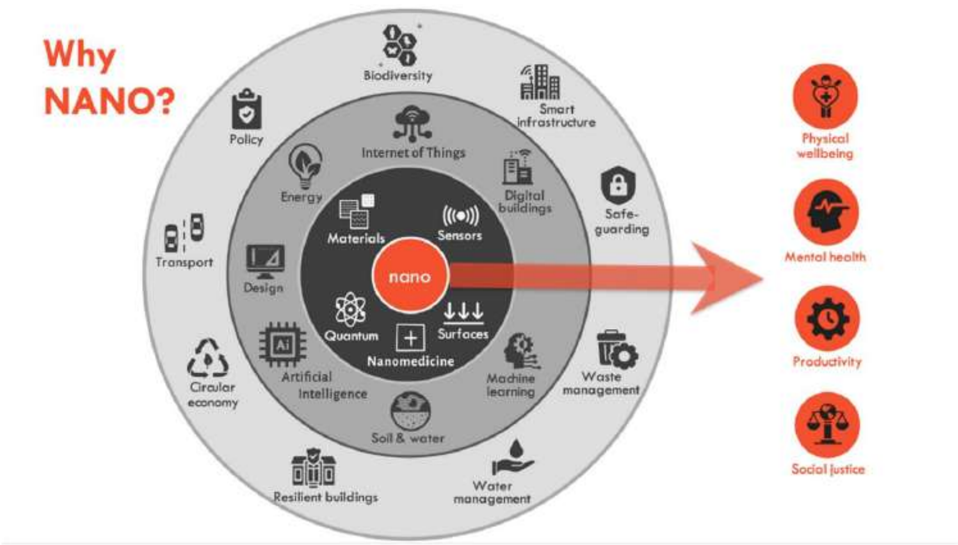

Fig. 1: Introduction of Nanotechnology [1]

ARCHITECTURES AND KEY COMPONENTS

Architectural Paradigms of 2025

Gate-All-Around (GAA) and Nanosheets: Replacing the decade-old FinFET, GAA architectures provide full electrostatic control of the channel, enabling reduced leakage and improved power efficiency [6].

Memory-Centric and Processing-in-Memory (PIM): These architectures minimize data movement between memory and processors, significantly improving energy efficiency in AI workloads [7].

Neuromorphic Hardware: Brain-inspired architectures that use nanoscale elements to enable low-power, real-time computation [8].

3D Vertical Scaling and CFETs: Vertical stacking of transistors enables higher density and performance while reducing chip footprint [9].

RESEARCH TRENDS AND FUTURE PROSPECTS

Vertical-Transport Nanosheets: These devices reduce channel length and improve electrostatic control, enabling continued scaling beyond conventional limits [10].

Quantum-Dot Cellular Automata (QCA): A paradigm using charge position instead of current flow, offering ultra-low power computation [11].

DNA-Based and Hybrid Electronics: Integration of biological molecules for ultra-dense and energy-efficient electronic systems [12].

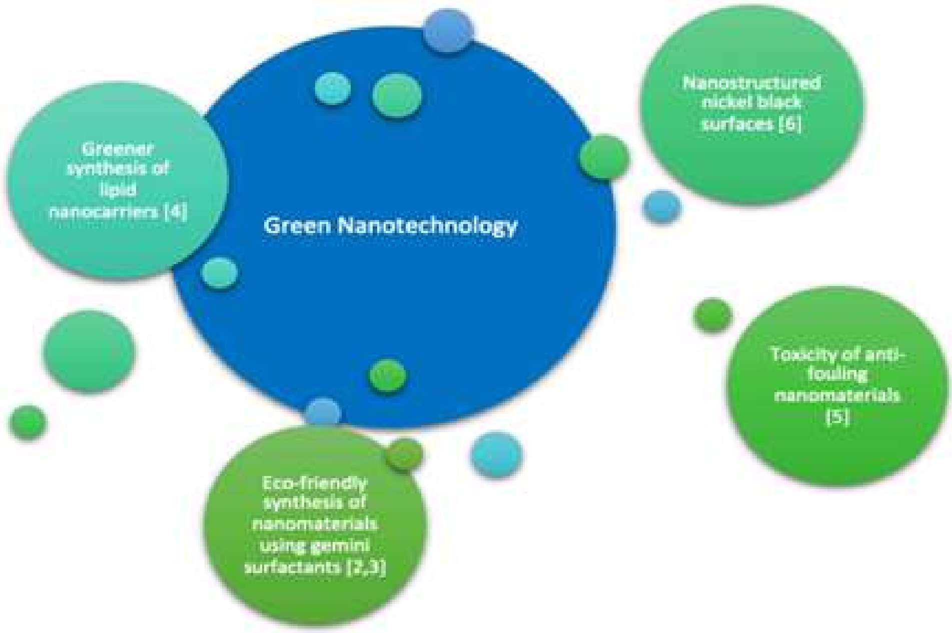

Fig. 2: Future nanotechnology applications [2]

ADVANTAGES

- Miniaturization and higher integration density.
- Enhanced performance and faster switching speeds.
- Reduced power consumption and improved efficiency.
- Improved material strength and durability.
- Support for next-generation energy solutions.

DISADVANTAGES

- Health and environmental risks due to nanoparticle exposure.
- High fabrication and development costs.
- Lack of standardized safety regulations.
- Complex manufacturing processes.

APPLICATIONS

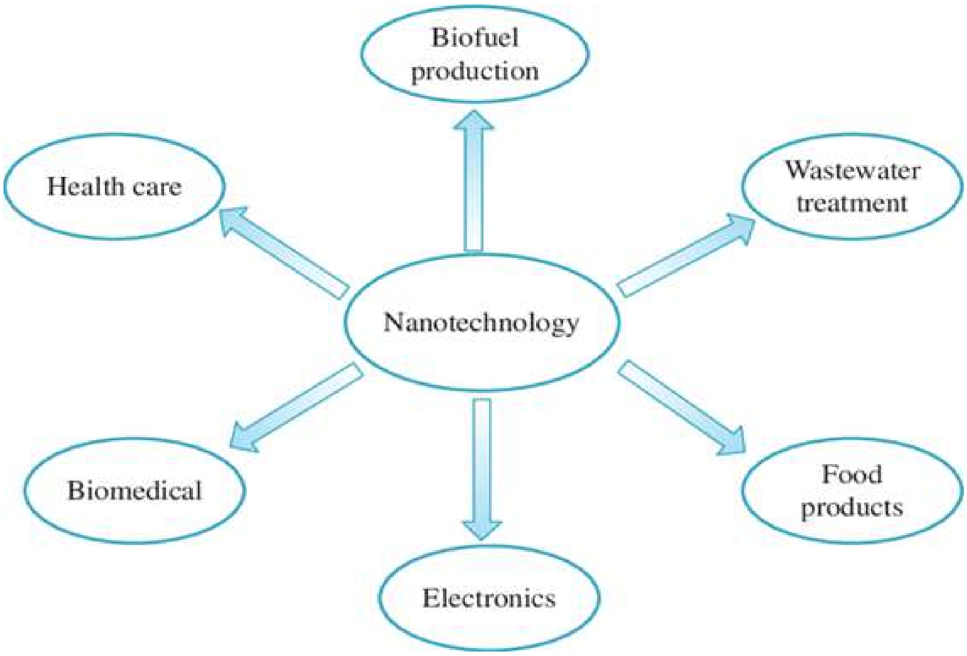

Fig. 3: Application of Nanotechnology [3]

- Smart infrastructure and monitoring systems.
- Medical diagnostics and bio-sensing devices.
- Defense and aerospace technologies.
- Precision agriculture and environmental monitoring.
- High-performance and edge computing systems.

CONCLUSION

Nanotechnology is redefining the future of electronics by enabling powerful, energy-efficient, and compact systems. Through innovations such as GAA transistors, 3D integration, and advanced materials, the limitations of conventional scaling are being overcome. As research progresses, nanotechnology will continue to drive breakthroughs across computing, energy, and healthcare sectors.

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COMMUNICATION

A LOSSY COPLANAR EBG STRUCTURE FOR ANTI-RESONANCE SUPPRESSION AND STOPBAND EXTENSION

Karthikeyan N
Student, S8 B.Tech (ECE)
Vidya Academy of Science and Technology
Department of Electronics & Communication Engineering
Kerala, India

Abstract

Power integrity has become a major challenge in modern high-speed electronic systems due to increased switching speeds and dense circuit integration. Conventional decoupling techniques are limited by parasitic inductance and anti-resonance effects. This article presents a study on a lossy coplanar electromagnetic bandgap (EBG) structure embedded with resistive-capacitive (RC) components to suppress anti-resonance and extend the stopband to low frequencies. By introducing controlled loss into the EBG structure, cavity resonances and anti-resonant peaks are effectively damped. The proposed structure achieves wideband noise suppression while maintaining signal integrity, making it suitable for practical printed circuit board (PCB) power distribution networks.

Introduction

With the rapid growth of high-speed digital and mixed-signal circuits, power distribution networks (PDNs) are increasingly affected by simultaneous switching noise and electromagnetic interference. Traditional approaches rely on decoupling capacitors to maintain low impedance; however, their effectiveness is restricted to low frequencies due to parasitic inductance.

Electromagnetic bandgap (EBG) structures have emerged as an effective solution for suppressing power noise over a wide frequency range. Coplanar EBG structures are particularly attractive due to their planar nature and ease of fabrication. However, when decoupling capacitors are introduced, severe anti-resonance occurs, which degrades low-frequency noise suppression.

This work focuses on a lossy coplanar EBG structure that integrates periodic RC components to eliminate anti-resonance and enhance stopband performance.

Lossy Coplanar EBG Structure

A coplanar EBG structure consists of periodic metal patches connected by narrow bridges on the power plane. The periodicity creates a stopband that prevents noise propagation. However, the structure behaves like a high-Q resonant cavity, resulting in strong resonances.

To overcome this limitation, lossy RC components are embedded periodically between the EBG patches. The resistors introduce damping, while capacitors provide DC isolation. This combination increases the effective conductivity of the dielectric and significantly reduces the Q-factor of the power-ground plane pair.

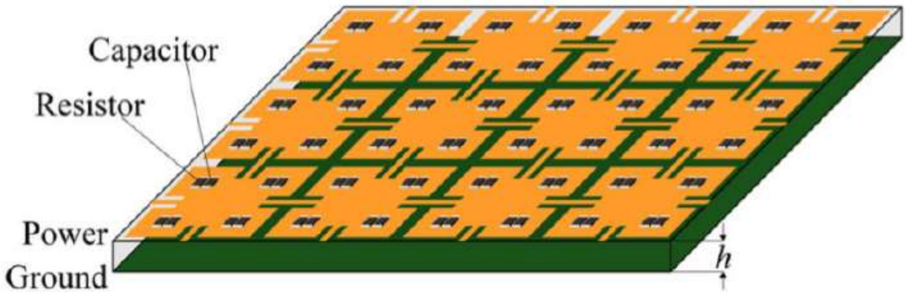

Fig. 1: Proposed lossy coplanar EBG structure with embedded RC components [1]

Working Principle

The addition of resistors suppresses anti-resonance by damping parallel resonant peaks formed between planar capacitance and parasitic inductance. Unlike conventional EBG structures that rely on long and narrow bridges for stopband extension, the proposed structure achieves low-frequency suppression without increasing bridge inductance.

As a result, shorter and wider bridges can be used, reducing IR drop and improving signal integrity.

Applications

The proposed lossy coplanar EBG structure is suitable for:

- Power integrity improvement in high-speed PCBs
- Noise suppression in mixed-signal systems
- EMI reduction in communication and computing hardware
- Advanced packaging and multilayer PCB designs

Advantages

- Effective suppression of anti-resonance
- Wide stopband extending to sub-MHz frequencies
- Improved signal integrity
- Practical implementation with low additional cost

Conclusion

A lossy coplanar EBG structure embedded with periodic RC components has been presented for anti-resonance suppression and wideband noise mitigation. The proposed approach significantly improves low-frequency stopband performance while maintaining good signal integrity. Due to its simplicity and effectiveness, the structure is well suited for modern high-speed electronic systems.

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A ROAD TOWARDS 6G COMMUNICATIONS-A REVIEW OF 5G ANTENNAS ,ARRAYS AND WEARABLE DEVICES

Ayush Nandakumar
Student, S8 ECE B.Tech (2022-26)
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

The future communication systems and wearable technology seek to realize high degrees of reliability. Communication systems are data rates, low energy usage, and the large number of connections, because of the massive increase in terms of the number of Internet-of-Things (IoT) and wearable devices. The devices will be used for various types of services such as cellular, environment, telemedicine, biomedical, smart traffic, etc. Consequently, it has been difficult for contemporary communication gadgets to support this many services. The motivation and potential of 6G are briefly given in this paper. communication system and the description of its major characteristics. Following that, the current status on the state-of-the art of 5G antenna technology, which encompasses the current 5G antennas and arrays, as well as 5G wearable antennas, is provided. In addition, the useful approaches and techniques of existing antenna design works, which would appropriately reduce the concerns of the new 5G and 6G systems, have been discussed. The major characteristics of wearable antennas designed for new technology are also mentioned at the end of this paper.

Introduction

The mobile data traffic globally has experienced an astonishing rise in recent years owing to high demand insecure, fast, and large data transmission rates in many recent and advanced Applications such as broadcast, Internet of Things (IoT), automobiles, smart cities,energy, emergencies communication, and wearable devices. This has brought a lot of pressure based on the current 3G/4G/WhatsApp systems in order to enhance their capacity and performance. Each succeeding generation of mobile and wireless communication systems has have been established to address these requirements. However, the data-hungry gadgets utilized in the mentioned applications above have increased greatly and demand a massive data rate .One possible means of improving capacity and data rates in the current and future mobile) and wireless generations, bandwidth . These speeds are in direct proportion to the bandwidth. The higher bandwidth offers higher data transfer rates . Nevertheless, contemporary frequency bands, namely 1.7 GHz GSM band, 1.8 GHz 4G/LTE band, 2.0 GHz 2.1 LTE band & 2.6 GHz band have a limited bandwidth. In recent times, high frequency frequency bands such as 24 GHz (n258), 28 GHz (n257 and n261), 37 GHz (n260), and 39 GHz (n280) besides some suggested future bands, for instance, 47 and 60 GHz bands have been evaluated for 5G applications . These high frequency bands, also referred to as “mm-wave bands,”provide considerably large bandwidth (in excess of 500 MHz). However, the current It still supports communication using the sub-6 GHz band. This includes the frequency range of 3.3 GHz to 4.2 GHz. The band is 4.4 GHz to 5 GHz (n79). The 5G bands are described in Figure 1. Although, some progress has been made, for instance, the utilization of a more advanced and bigger number of multiple-input multiple-output (MIMO) antennas to enhance wireless.

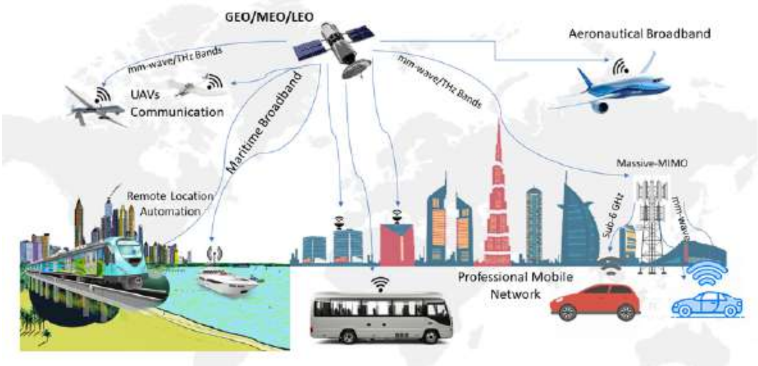

Fig. 1: Diagram of integrated 5G/satellite 6G communication system vision.(1)

Key Features of 6G Communication

Some of The Key Features Includes:

- **Connectivity:** A major aspect of the evolution from 5G to 6G would be massive connectivity. A tremendous number of IoTs are expected to be interconnected with each other either in line of sight or non-line of sight scenarios. Uninterrupted connectivity will be achieved using artificial-intelligent-assisted reconfigurable meta-surfaces. Connectivity in large areas is expected to be achieved using integrated satellite and 5G networks.
- **Mobility:** Highly intelligent transport systems operating at extremely high speeds are anticipated. Ultra-low Data communication latency will also contribute to enhancing the transportation system. The peak The speeds taken into consideration in 6G are Speed of 1000 Km/h in airline communication.is significantly higher than 5G
- **Security:**Data privacy and security are key components of every communication system.especially within the defense industry and banking sector, and this is evident from Figure 3. In applying deep Learning and artificial intelligence technology in the physical or network layers, thesecurity will be enhanced in deceives, infrastructures, and assets in 6G networks .
- **Broadcasting:**New multimedia services and infrastructures with the focus on ultra High video streaming, live broadcasting, and entertainment would be facilitated in 6G. The result will be that excellent quality of service by combining satellites, cables, and mobile technologies.
- **Ubiquity:**It shall be larger in coverage area compared to the 5G systems. The Spatial and maritime communications, besides terrestrial ones, will be the part of 6G systems.based communication to achieve large coverage and higher data rates. The sensor node will be The available combination of GEO/LEO satellite and terrestrial networks. This is very much important, especially for communication in airplanes, ships, and people.living/working in remote areas.
- **Data Rates:**Shannon's equation states that the data rates are directly proportional to Capacity can be enhanced by improving bandwidth and the number of antennas. The mm-wave/THz bands provide considerably high bandwidth from 1 to 10 GHz. Hence,For both techniques, a very large number of antennas and a Mm-wave/THz band are used directly.ways in which higher demand for data rates can be achieved. It can reach up to 1 Tbps.which is higher than 5G in both up and downlinks . The higher data rates are significant in nearly all fields: from ultra-high-definition video streaming to big

data files in offices, etc.

Fig. 2: key features of the 6G communication systems.(2)

Applications of 6G Communication

- **Ultra-High Data Rate Services:** Data rates in terabits per second are envisaged to support ultra-HD video, holographic communication, and immersive experience in AR/VR/XR.Enabling seamless interactions with the cloud and real-time AI services thanks to ultra-high throughput will be possible.
- **Massive IoT Connectivity:** 6G will connect billions of devices, including sensors, smart infrastructure, vehicles, and biomedical wearables-far beyond current 5G capacity. Wearable antennas integrated into clothing, medical sensors, and accessories will offer continuous connectivity.
- **Intelligent Transportation** & **Autonomous Systems :**The autonomous vehicles, drones, V2X communications, and coordinated robotic systems are some examples of very-low-latency applications that will be supported by ultra-high-speed networks.Real-time sensing and decision-making will be possible across dynamic environments.
- **Telemedicine** & **Remote Healthcare:**Remote surgeries, real-time health monitoring, and AI-assisted diagnosis will rely on ultra-reliable low-latency 6G links. Wearable antennas and devices would be the central players in continuous health data collection and urgent response.
- **Space-Integrated Networks:**The 6G technology looks forward to integrating terrestrial communications with satellite and aerial communications for broadband coverage even in oceans and difficult terrains.
- **Smart Cities** & **Infrastructure:**6G shall form the basis of smart city applications: traffic flow management, energy grid control, security solutions, environmental applications, and so on Dense sensor networks and communication-sensing integration will improve intelligentization of cities.
- **Environmental** & **Industrial Sensing:**The networks will also serve not only as communication means but also as sensing systems of high resolutions applicable in environmental sensing, industrial control, and surveillance through communication-sensing technologies.

Fig. 3: The frequency spectrum in 6G communication.(3)

5G Wearable Devices

Wearable technology has experienced a huge demand in the past ten years. The number of mBed-enabled wearable electronic devices has grown more than 100% in the over last 4 years, increasing from 325 million in 2016 to approximately 720 million.

However, designing wearable antennas is quite challenging, and this is more so for 5G mm-Wave & IoT, where the fabrication tolerance is dependent on the frequency impact performance. To be appropriately integrated into wearable technology, antennas should be lightweight, flexible, durable, and able to perform well with only a small loss in the positationed close to the human body. As tissues of the human body absorb signals naturally and tend to attenuate antenna gain, the operating conditions are of prime importance. Further,antennas must be able to operate effectively in bending or motion scenarios. This Choosing substrates and conducting materials appropriately is also critical; they should facilitate mechanical flexibility (bending, wrapping, or even washing) while retaining adequate electrical Performance.

- **IoT (Internet of Things):**Worn antennas integrate the human body with the IoT environment,Example: Smart sensors,Smart homes,Industrial IoT
- **Sports:** Wearable antennas are used in fitness bands, smart jerseys, and wrist devices Used to monitor:Heart rate Speed Fatigue,Movement accuracy.
- **Telecommunication:** It facilitates uninterrupted wireless communication between users, base stations, and cloud services.Supports,Voice,Video,Data transmission Particularly useful for mobile users in a dynamic environment.
- **Health Remote:**One of the most important uses.Wearable antennas receive and relay physiological signals including:ECG,Blood pressure,Oxygen saturation$</s$,Body temperature.
- **Medicine:**Incorporates telemedicine, smart implants, and medical wearables.Supports:Diagnoses through Artificial intelligence in healthcare Emergency alerts
- **Wellness:**Well Emphasis on day-to-day health, life, and mental wellness.Examples: Sleep tracking,Sleep,Stress Monitoring Calorie and activity tracking

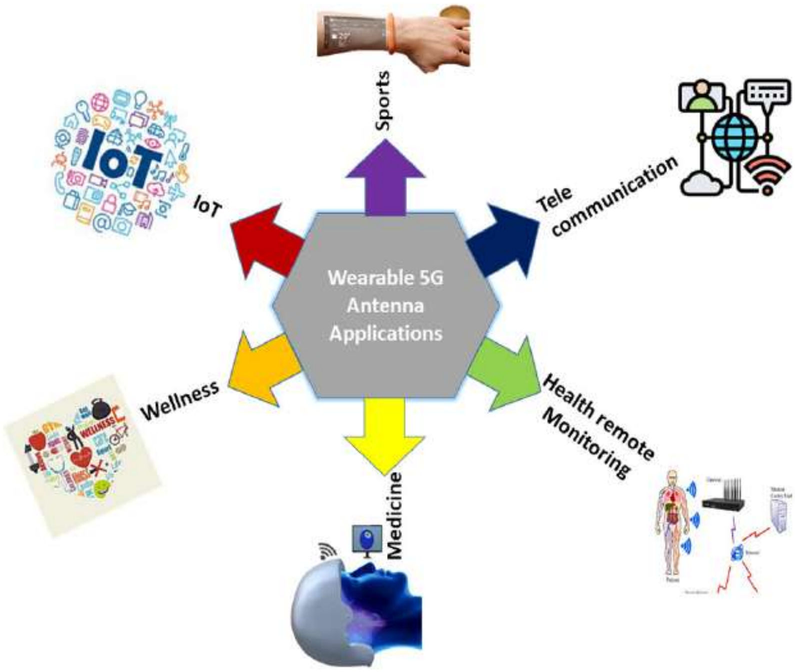

Fig. 4: llustration of wearable antenna applications.(4)

Future Prospects and Conclusion

The trend in the development of communication systems in the 6G era is being led by the advancement in the field of 5G antennas, antenna arrays, and wearable antennas. The future may hold the use of the sub-terahertz and terahertz frequency bands in achieving the highest possible data transfer rates, the development of smart and reconfigurable antenna arrays using AI-powered beamforming, and the use of wearable textiles based on antennas for the purpose of always-connected communication. The fusion of communication and sensing functionality, the use of low-power or energy-harvesting schemes for increased energy savings, and the development of space-air-ground integrated networks are also possible future aspects. In summary, despite the existing issues in path loss, power consumption in the communication device, human safety assurance, and complexity in the communication systems needed in the future, research in the field of wearable antennas in the 5G category is giving possibilities something can be developed in the future towards the 6G generation to render ultra-reliable low latency and human-centric communication.

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HAM RADIO: A RELIABLE COMMUNICATION SYSTEM DURING DISASTERS

Alen.M.A
(Amateur Radio Station Operator)
Student, S8 ECE A.Tech (2022–26)
Department of Electronics & Communication Engineering
Vidya Academy of Science and Technology
P.O. Thalakkottukara, Kerala, India

Abstract

In today's digital era, communication has become an essential part of daily life, with mobile phones serving as the primary medium of interaction. However, during natural disasters such as earthquakes, tsunamis, and cyclones, conventional communication systems often fail due to infrastructure damage. In such situations, Amateur Radio, commonly known as HAM radio, plays a crucial role in enabling reliable communication. This paper discusses the importance of HAM radio as an emergency communication system, its working principles, licensing requirements, and real-world applications. The role of amateur radio operators in disaster management and emergency response is also highlighted, emphasizing its relevance in modern society.

Introduction

Mobile phones have become an indispensable part of human life. Communication through calls, messages, and internet services has made information exchange instantaneous and convenient. However, this convenience heavily depends on communication infrastructure such as cellular towers, power grids, and internet connectivity. During natural disasters such as earthquakes, floods, cyclones, and tsunamis, these systems often fail, leaving people isolated and unable to communicate.

In such critical situations, radio communication emerges as a reliable alternative. Unlike conventional networks, radio communication does not depend on centralized infrastructure. A simple transmitter, antenna, and power source are sufficient to establish communication. This makes Amateur Radio a vital tool during emergency and disaster relief operations.

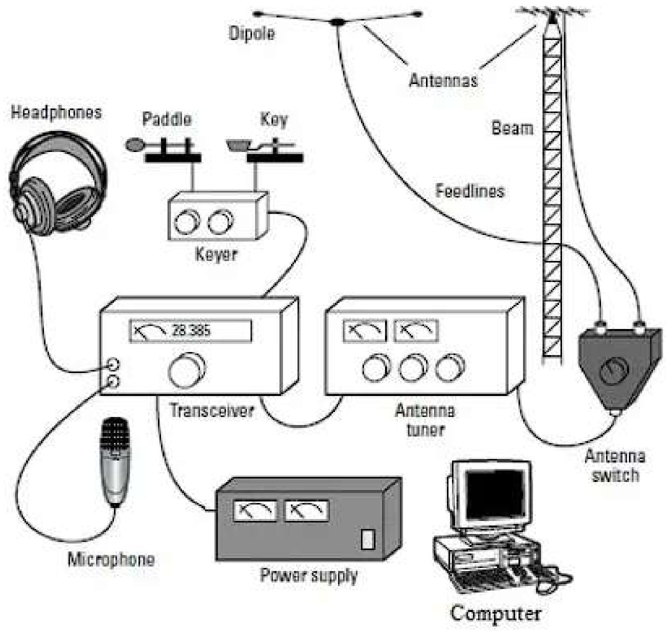

Fig. 1: Basic HAM Radio Communication Setup

Overview of HAM Radio

HAM radio, also known as Amateur Radio, is a non-commercial radio communication service operated by licensed individuals. It allows users to communicate locally, nationally, and internationally using various frequency bands. Operators communicate using voice, Morse code, and digital modes.

To operate a HAM radio legally, an individual must obtain a license issued by the national telecommunications authority. The licensing process involves understanding basic electronics, radio wave propagation, operating ethics, and safety procedures. Until obtaining a license, individuals may only listen to transmissions as Short Wave Listeners (SWLs).

One unique aspect of HAM radio is the assignment of a call sign to every licensed operator. This call sign acts as a global identity, ensuring accountability and structured communication.

Role of HAM Radio During Disasters

HAM radio has played a significant role during many natural disasters worldwide. A notable example is the 2004 Indian Ocean tsunami, where HAM radio operators from the National Institute of Amateur Radio (NIAR), Hyderabad, were among the first to transmit critical information from the Andaman and Nicobar Islands when all other communication systems failed.

During emergencies, HAM radio operators assist government agencies, disaster response teams, and humanitarian organizations by providing real-time information, coordinating rescue operations, and relaying distress messages. Their ability to operate independently of existing infrastructure makes them invaluable during crisis situations.

Fig. 2: HAM Radio Communication During Disaster Management

Advantages of HAM Radio

- Operates without reliance on cellular networks or the internet.
- Effective during natural disasters and emergency situations.
- Encourages technical learning and experimentation in electronics.
- Enables global communication using minimal equipment.
- Promotes community service and emergency preparedness.

Future Scope and Conclusion

With the increasing frequency of natural disasters and growing dependence on digital communication, the importance of HAM radio continues to rise. Technological advancements such as digital modes, satellite-based amateur communication, and software-defined radios are expanding the capabilities of amateur radio systems.

In conclusion, HAM radio is not merely a hobby but a vital communication tool that serves humanity during critical times. It fosters technical knowledge, global connectivity, and social responsibility. Encouraging more individuals, especially students, to engage in amateur radio can significantly strengthen disaster preparedness and communication resilience.

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Positioning and Navigation Approaches Using Packet Loss-Based Multilateration for UAVs in GPS-Denied Environments

Amal Krishnan T
Student, S8 ECE B.Tech (2022-26)
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

Unmanned Aerial Vehicles (UAVs) are increasingly used in critical applications such as de- fense surveillance, disaster response, precision agriculture, and environmental monitoring. Accurate positioning and navigation are vital for these missions. While the Global Positioning System (GPS) remains the dominant method due to its global coverage and high accuracy, it faces serious limita- tions in environments where signals are weak, blocked, or intentionally disrupted. Factors such as jamming, spoofing, and multipath effects in urban or indoor areas make GPS unreliable, highlighting the need for alternative navigation strategies. Packet Loss-Based Multilateration (PLM) is an emerging technique that estimates a UAV's position using wireless communication signals. It leverages the relationship between distance and packet loss probability—where signal degradation with distance results in higher packet loss rates. By measuring these rates across multiple anchor nodes and applying multilateration algorithms, a UAV can estimate its position accurately without GPS or expensive hardware. This makes PLM a low-cost and scalable solution suitable for GPS-denied environments.

Compared to inertial or vision-based systems, PLM offers a balanced trade-off between accu- racy, cost, and robustness. It performs well in dynamic and cluttered environments and can be inte- grated with cooperative UAV networks to enhance reliability. However, challenges remain, including environmental interference, multipath effects, and model calibration issues. Ongoing research aims to overcome these limitations through adaptive algorithms and hybrid sensor fusion. Overall, PLM represents a promising direction for achieving resilient UAV navigation where GPS cannot be relied upon, ensuring operational continuity in mission-critical scenarios.

Introduction

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have emerged as one of the most transformative technologies in modern engineering applications. Over the past decade, UAVs have been widely adopted in areas such as disaster management, surveillance, environmental monitoring, precision agriculture, military reconnaissance, delivery systems, and smart city infrastructure. Their capability to operate autonomously without a human pilot onboard makes them highly efficient, cost-effective, and suitable for hazardous environments where human intervention is risky or impractical.

A fundamental requirement for fully autonomous UAV operation is accurate positioning and navigation. In most practical scenarios, UAVs rely on the Global Positioning System (GPS) to determine their real-time geographic coordinates. By receiving signals from multiple satellites and applying trilateration techniques, a drone can compute its position with high precision. This positioning information enables stable flight control, waypoint navigation, collision avoidance, and mission planning. However, despite its widespread usage, GPS-based localization suffers from significant limitations in certain environments.

GPS-denied environments refer to areas where satellite signals are either unavailable, severely degraded, or unreliable. Such conditions commonly occur in indoor facilities, underground tunnels, dense urban regions with high-rise buildings, forested areas, military-restricted zones, and disaster-affected locations. Signal attenuation, multipath interference, jamming, and physical obstructions can prevent drones from receiving accurate satellite data. In these circumstances, UAVs may experience incorrect localization, navigation drift, or complete loss of positional awareness, which can compromise mission safety and operational effectiveness.

To address these challenges, researchers have explored alternative GPS-independent localization techniques. Vision-based approaches such as Visual Odometry (VO) and Simultaneous Localization and Mapping (SLAM) use onboard cameras to estimate motion and map the environment. Although these methods provide high accuracy, they require complex image processing algorithms and significant computational resources. Similarly, sensor-fusion techniques employing LiDAR, inertial measurement units (IMUs), and Extended Kalman Filters (EKF) enhance positioning reliability but increase system cost, power consumption, and integration complexity. Radio Frequency (RF) fingerprinting and time-based packet transmission techniques have also been proposed; however, many of these approaches still require additional hardware or infrastructure support.

In contrast to sensor-intensive solutions, this work investigates a lightweight and infrastructure-efficient positioning strategy based solely on wireless packet loss information. Packet loss is a common phenomenon in wireless communication systems, where transmitted data packets fail to reach the receiver due to distance, interference, environmental noise, or channel fading. Importantly, empirical studies indicate that packet loss probability increases as the transmission distance increases. This proportional relationship between packet loss rate and distance can be exploited as an indirect distance estimation metric.

Building upon this observation, the proposed approach enables a UAV to estimate its position by analyzing packet loss rates from multiple reference nodes placed within a surveillance region. By correlating packet loss information with distance and applying a multilateration framework, the drone can approximate its real-time coordinates without relying on GPS or complex sensory equipment. Furthermore, to ensure reliable navigation toward a target destination, three heuristic navigation algorithms are introduced: Heading-Based Navigation (HBN), Clockwise-Sequential Navigation (CSN), and Pre-Decision Navigation (PDN). These algorithms are designed to operate under different levels of directional awareness and computational constraints.

The primary objective of this study is to develop a sensor-free, low-complexity localization and navigation methodology suitable for GPS-denied environments. By minimizing hardware dependency and leveraging existing wireless communication mechanisms, the proposed framework aims to provide a practical and scalable alternative for UAV surveillance and rescue operations. The remainder of this paper presents the system formulation, algorithm design, simulation architecture, performance evaluation, and comparative analysis of the proposed navigation strategies.

System Model and Problem Formulation

In order to enable positioning of an unmanned aerial vehicle (UAV) in a GPS-denied environment, a packet loss-based multilateration framework is considered in this study. The system consists of one target UAV whose position is unknown and a set of reference nodes deployed at fixed and known locations within a surveillance area. These reference nodes periodically broadcast wireless data packets, and the target UAV computes the packet loss rate corresponding to each reference node. The fundamental idea is to exploit the proportional relationship between packet loss probability and transmission distance to estimate the UAV's real-time location.

We consider a two-dimensional Euclidean surveillance region where n reference nodes are positioned at known coordinates $P_i = (x_i, y_i)$ for $i = 1, 2, \ldots, n$. The target UAV is located at an unknown position $\rho(t) = (x(t), y(t))$ at time t. During each transmission cycle, every reference node broadcasts a fixed number of packets T_i to the UAV. Due to environmental noise, interference, fading, and channel impairments, some packets fail to reach the UAV. Let $R_i(t)$ denote the number of successfully received packets from reference node i during time interval t.

The packet loss rate corresponding to reference node i is defined as:

$$PLR_i(t) = \frac{T_i - R_i(t)}{T_i} \tag{1}$$

The packet loss rate is assumed to increase proportionally with the distance between the UAV and the reference node. Let $dist_i(t)$ represent the true Euclidean distance between the UAV and reference node i. Based on empirical observations in wireless communication systems, packet loss probability increases as transmission distance increases. Therefore, an approximate linear correlation between distance and packet loss rate is modeled as:

$$dist_i(t) \approx PLR_i(t) \times r_{max} \tag{2}$$

where r_{max} represents the maximum communication range at which packet loss approaches 100%. This linear scaling aligns the bounded packet loss interval $[0, 1]$ with the spatial distance range $[0, r_{max}]$, enabling distance estimation directly from packet loss measurements.

Fig. 1: Conceptual illustration of packet loss-based multilateration in a two-dimensional surveillance area. The UAV estimates its position by computing distances from multiple reference nodes using packet loss information.

As illustrated in Fig. 1, each estimated distance defines a circle centered at the corresponding reference node. Using the estimated distances, the UAV position can be determined through multilateration. For each reference node i, a circle equation centered at (x_i, y_i) with radius $dist_i(t)$ is given by:

$$(x - x_i)^2 + (y - y_i)^2 = (PLR_i(t) \cdot r_{max})^2 \tag{3}$$

By combining multiple such circle equations from at least three reference nodes, the intersection point provides an estimate of the UAV's position. However, due to environmental noise and estimation inaccuracies, an exact geometric intersection may not exist. Consequently, the multilateration problem is reformulated as a linear system and solved using linear algebra techniques such as Singular Value Decomposition (SVD). This method computes a least-squares solution that minimizes the overall positioning error.

The problem formulation therefore consists of two primary objectives. The first objective is accurate estimation of the UAV position using packet loss-based multilateration. The second objective is the development of an efficient navigation strategy that guides the UAV toward a desired destination once its position is estimated. Because packet loss measurements are affected by environmental uncertainty, the navigation mechanism must be robust against imperfect distance estimation.

This formulation provides a lightweight and sensor-free alternative to conventional GPS-independent localization techniques and forms the mathematical foundation for the navigation algorithms discussed in the following section.

Proposed Navigation Algorithms

After estimating the UAV position using packet loss-based multilateration, the next step is to guide the UAV toward the desired destination. Since position estimation may contain errors due to environmental noise, the navigation strategy must be robust and adaptive. Three heuristic navigation algorithms are proposed:

- **Heading-Based Navigation (HBN):** Assumes the UAV has directional information (e.g., gyroscope). The UAV adjusts its heading directly toward the target, resulting in faster convergence and reduced navigation error.
- **Clockwise-Sequential Navigation (CSN):** Designed for cases without directional awareness. The UAV rotates sequentially with a fixed angular shift and evaluates navigation error after each movement, following a trial-and-error strategy.
- **Pre-Decision Navigation (PDN):** Predicts multiple possible future positions and selects the direction that minimizes the predicted navigation error. This improves efficiency but requires slightly higher computation.

These algorithms ensure reliable UAV navigation in GPS-denied environments under different operational constraints.

Simulation and Performance Evaluation

To validate the effectiveness of the proposed packet loss-based positioning and navigation framework, a simulation model was developed to replicate UAV operation in a GPS-denied surveillance environment. A two-dimensional square region of 1000 m × 1000 m was considered, with four reference nodes placed at the corners of the surveillance area. These reference nodes continuously broadcast wireless packets to the UAV, enabling packet loss computation for distance estimation.

The UAV was initially commanded to move toward a predefined destination located at the center of the surveillance region. However, due to environmental noise and packet transmission uncertainty, the UAV deviated from its intended position. The proposed multilateration model was then applied to estimate the actual UAV position using packet loss rates from all reference nodes. The navigation algorithms—Heading-Based Navigation (HBN), Clockwise-Sequential Navigation (CSN), and Pre-Decision Navigation (PDN)—were subsequently used to guide the UAV back to the desired destination.

Environmental noise was modeled using a uniform distribution to simulate realistic wireless channel conditions. A threshold distance of 5 meters was defined as the stopping criterion, meaning the UAV successfully reached the destination when the estimated error fell below this limit.

The simulation results demonstrate that the HBN algorithm provides the most direct navigation path when directional information is available, resulting in faster convergence to the destination. The CSN algorithm, although slower due to its sequential trial-based approach, successfully navigates the UAV without requiring orientation sensors. The PDN algorithm improves efficiency by pre-evaluating candidate directions, achieving a balance between computational complexity and navigation accuracy.

Overall, the proposed framework achieved an average reduction of approximately 55.78% in navigation error compared to uncontrolled movement in GPS-denied conditions. The results confirm that packet loss information alone can serve as a reliable metric for positioning and navigation without relying on GPS, vision-based systems, or additional sensory hardware.

Applications

The proposed packet loss-based positioning and navigation framework has several practical applications in GPS-denied environments:

- **Indoor Surveillance:** Enables UAV localization inside warehouses, factories, shopping malls, and industrial buildings where GPS signals cannot penetrate.
- **Tunnel and Underground Inspection:** Suitable for tunnel monitoring and mining operations where satellite signals are completely unavailable.
- **Disaster Response and Rescue:** Assists UAV navigation in earthquake-affected or collapsed areas where infrastructure damage blocks GPS reception.
- **Military Reconnaissance:** Supports autonomous operation in restricted or signal-jammed regions without relying on external satellite connectivity.
- **Smart Cities and IoT Systems:** Facilitates inspection of power lines, bridges, pipelines, and urban infrastructure using existing wireless networks.

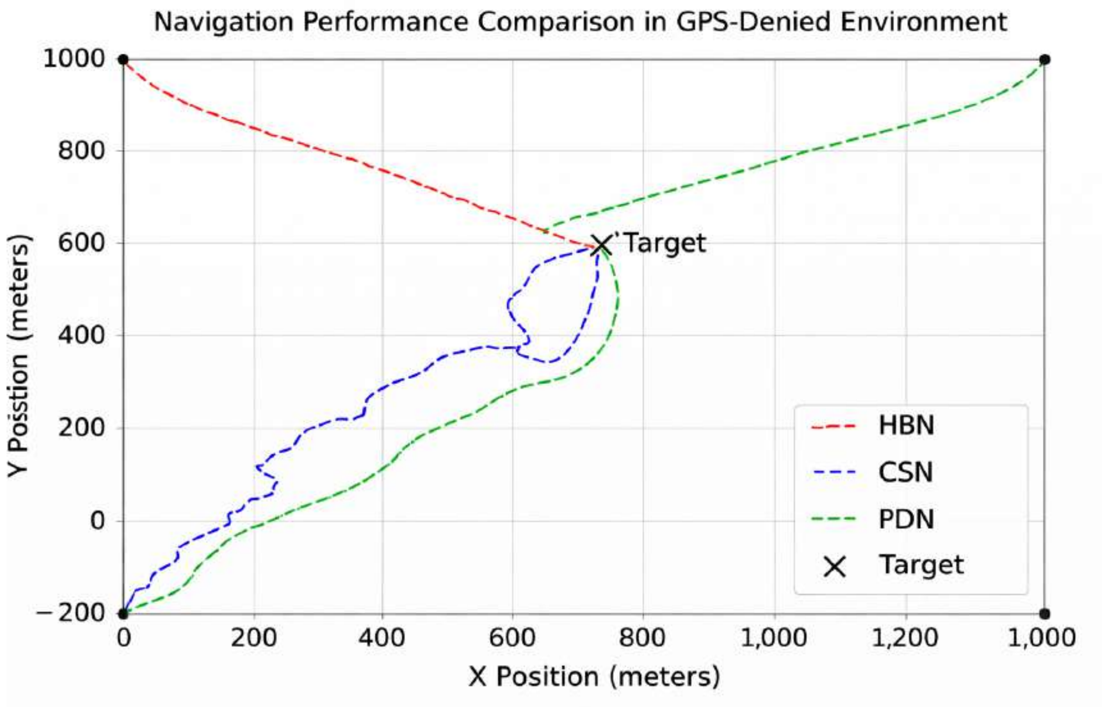

Fig. 2: Comparison of navigation trajectories using HBN, CSN, and PDN algorithms in a GPS-denied environment.[1]

The lightweight and sensor-free nature of the proposed system makes it suitable for low-cost drones with limited payload capacity.

Conclusion

This paper presented a packet loss-based multilateration framework for positioning and navigation of unmanned aerial vehicles in GPS-denied environments. Instead of relying on satellite signals or sensor-intensive techniques such as visual SLAM, LiDAR, or inertial fusion systems, the proposed method exploits the proportional relationship between wireless packet loss rate and transmission distance to estimate UAV position. By applying multilateration and linear algebra-based estimation techniques, the UAV is able to approximate its coordinates using only communication signals from reference nodes.

To ensure reliable movement toward a desired destination, three heuristic navigation algorithms—Heading-Based Navigation (HBN), Clockwise-Sequential Navigation (CSN), and Pre-Decision Navigation (PDN)—were introduced. These algorithms provide flexibility under varying operational constraints, allowing navigation both with and without directional orientation information. Simulation results demonstrated that the framework achieves significant navigation error reduction, confirming that packet loss information alone can serve as an effective positioning metric in GPS-denied conditions.

The proposed approach offers a lightweight, low-cost, and sensor-free alternative to traditional GPS-independent localization methods. Although environmental noise and communication uncertainty may introduce estimation errors, the overall system maintains stable convergence toward the target position. Future work may focus on extending the model to three-dimensional positioning, improving distance estimation accuracy using adaptive channel modeling, and implementing the framework on real UAV hardware platforms for real-time validation.

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Electromagnetic Interference with Mobile Communication Devices in UAVs and Its Countermeasures

Aparna Gopinath
Student, S8 ECE B.Tech (2022–2026)
Vidya Academy of Science and Technology
Department of Electronics and Communication Engineering
Kerala, India

Abstract

The rapid expansion of unmanned aerial vehicles (UAVs) in industrial applications such as surveillance, delivery, and inspection has increased their dependence on reliable wireless communication systems. However, electromagnetic interference (EMI), particularly selfjamming caused by onboard electronics like motors, power circuits, and sensors, poses a serious challenge to communication stability. This study investigates the impact of EMI on mobile communication modules operating at 800 MHz, 1800 MHz, and 2100 MHz. Experimental results reveal significant receiver sensitivity degradation, with a maximum loss of approximately 29 dB in the 800 MHz band, which is critical for long-range communication and control. To address this issue, mechanical redesign, improved power distribution, and enhanced shielding techniques were implemented. These countermeasures successfully eliminated measurable performance degradation. The findings emphasize the importance of electromagnetic compatibility in UAV design and demonstrate that effective EMI management can ensure safe, stable, and reliable UAV operation in industrial environments

1. Introduction

Unmanned Aerial Vehicles (UAVs) are increasingly being deployed across various industrial sectors, including surveillance, inspection, delivery services, and communication support. Their ability to operate in remote or challenging environments makes them highly valuable for modern applications. A key factor behind their effectiveness is the use of reliable wireless communication systems, which enable real-time control, navigation, and data transmission. However, as UAV platforms incorporate multiple electronic components within a compact structure, they become susceptible to electromagnetic interference (EMI). In particular, selfgenerated electromagnetic noise from onboard systems such as motors, power circuits, and sensors can interfere with mobile communication modules. This internal interference, known as self-jamming, can reduce signal strength,

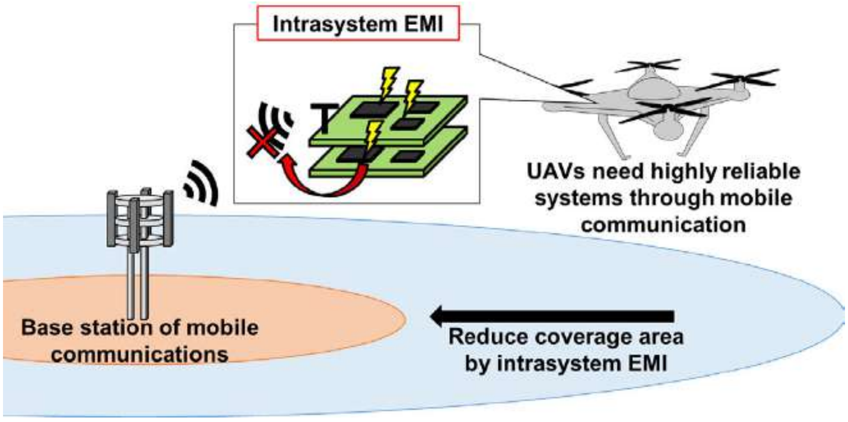

Figure 1: [1] EMI problems inside UAVs reducing coverage

degrade receiver sensitivity, and potentially affect flight safety.Therefore, understanding and mitigating EMI is essential for ensuring stable communication performance and safe UAV operation. Proper electromagnetic compatibility considerations during the design and development stages play a crucial role in enhancing system reliability and overall performance.

2. Experimental Setup for EMI Evaluation

To investigate the impact of EMI, experiments were conducted in a controlled anechoic chamber environment to eliminate external electromagnetic noise and reflections. The UAV was prepared by removing its propellers for safety and was powered using a regulated external power supply to ensure stable operation. LTE signals were generated in three frequency bands 800 MHz, 1800 MHz, and 2100 MHz using a base station tester. Receiver performance was evaluated by measuring sensitivity, throughput, and block error rate. Multiple antenna positions were tested around the UAV body to determine the worst-case interference conditions, ensuring accurate and repeatable analysis.

2.1 Environment

The experiment was conducted inside a shielded anechoic chamber to eliminate external electromagnetic interference and signal reflections. This controlled environment ensured that only the EMI generated by the UAV itself was measured accurately and consistently.

2.2 UAV Setup

The UAV was prepared by removing its propellers for safety during indoor testing. It was powered using a regulated external power supply instead of its onboard battery to maintain stable operating conditions and reduce additional noise sources.

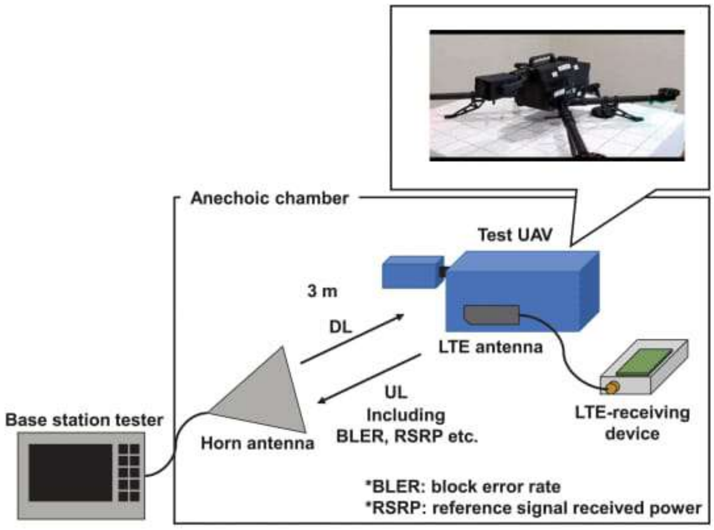

Figure 2: [1] EMI evaluation setup with base station tester

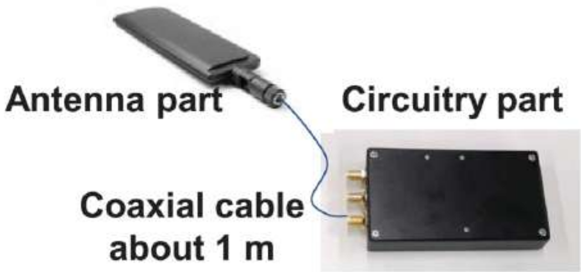

Figure 3: [1] LTE receiver setup

2.3 Signal Source

LTE communication signals were generated using a base station tester at 800 MHz, 1800 MHz, and 2100 MHz frequency bands. These signals simulated real mobile network conditions to evaluate communication performance under EMI exposure

2.4 Receiver

The receiver system consisted of a communication antenna and RF front-end circuitry. Its performance was evaluated by measuring receiver sensitivity and signal quality parameters under different interference conditions.

2.5 Antenna Positions

The communication antenna was tested at multiple locations around the UAV structure. This helped identify the worst-case positions where electromagnetic noise had the strongest impact.

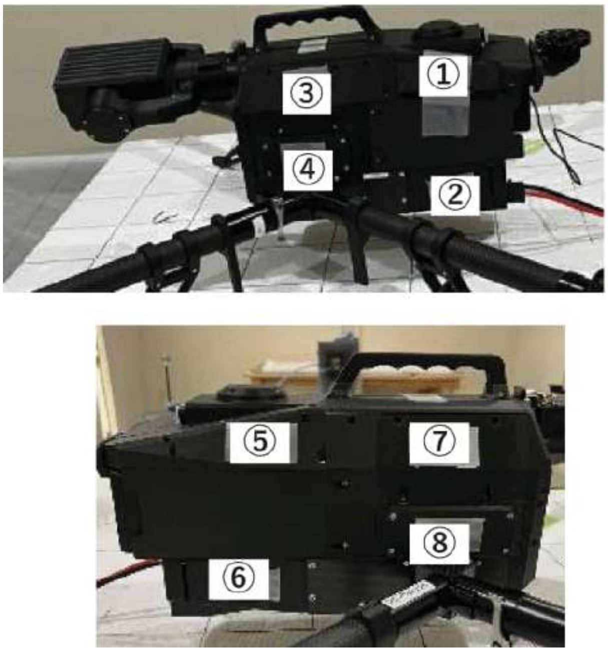

Figure 4: [1] Antenna positions for measuring EMI impact

3. EMI Noise Components Inside UAVs

Detailed analysis revealed that several internal components contribute to EMI within the UAV. DC–DC power converters generate switching harmonics that extend into communication frequency bands. Control circuits and microcontroller oscillators produce discrete-frequency noise, while camera modules and high-speed HDMI interfaces emit broadband electromagnetic radiation. Since these components are densely packed within the UAV chassis, their emitted noise can couple directly into the communication antenna, degrading signal quality and reducing receiver performance

4. Impact of EMI on Communication Performance

Experimental results showed significant receiver sensitivity degradation across all tested frequency bands. The most severe degradation was observed in the 800 MHz band, where sensitivity was reduced by approximately 29 dB. The 1800 MHz and 2100 MHz bands experienced degradations of about 10 dB and 15 dB, respectively. Because the 800 MHz band is essential for long-range communication and stable control links, such degradation can significantly reduce communication range and increase the risk of connection loss during UAV operation.

5. Engineering Countermeasures

To mitigate EMI effects, several countermeasures were implemented at both circuit and mechanical levels. The printed circuit board was redesigned using a four-layer structure with improved grounding and bypass capacitors. Shielding techniques were applied to high-speed cables such as HDMI and USB connections. Conductive plating was added to the UAV chassis, and localized shielding was used for noisy components like DC–DC converters. Antenna placement was also optimized to minimize exposure to interference sources. These improvements reduced EMI levels by up to 26 dB and restored communication performance to near-normal conditions.

5.1 PCB Improvements

Upgrading the printed circuit board significantly reduced EMI in the UAV system. The original two-layer boards were replaced with four-layer PCBs to improve grounding and minimize noise coupling into sensitive circuits. Bypass capacitors were added near switching components, and optimized crystal oscillators were used to reduce harmonic noise. These improvements enhanced isolation between power and signal lines, effectively limiting the spread of interference.

5.2 Cable Shielding

High-speed cables, especially HDMI connections from camera modules, were major sources of EMI. To reduce this, EMI suppression mesh was applied to HDMI cables to block broadband radiation. Noisy re-drivers were minimized, and shielded coaxial cables were used for USB-C interfaces. These shielding measures significantly reduced radiated emissions and overall interference within the UAV system.

5.3 Localized Component Shielding

High-noise components such as the DC–DC converter were enclosed with localized metal shielding to contain the strong harmonics they generated. A metal cover was installed over the converter to prevent interference from spreading to nearby circuits. This approach effectively reduced high-frequency EMI, as switching regulators are among the primary sources of internal noise in UAV systems

5.4 Chassis Shielding

The UAV chassis was enhanced with conductive plating to act as an electromagnetic shield, reflecting and absorbing noise before it reached sensitive components. This structural shielding reduced radiation from multiple modules at once. Additionally, antenna

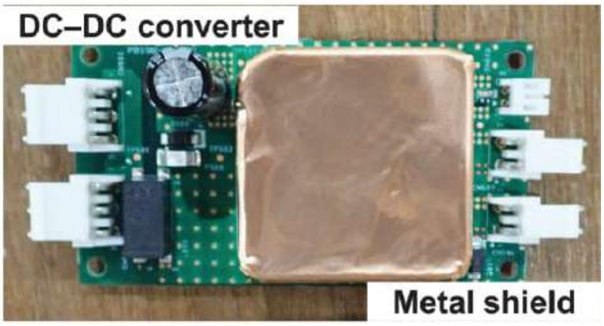

Figure 5: [1] DC–DC Converter Shielding

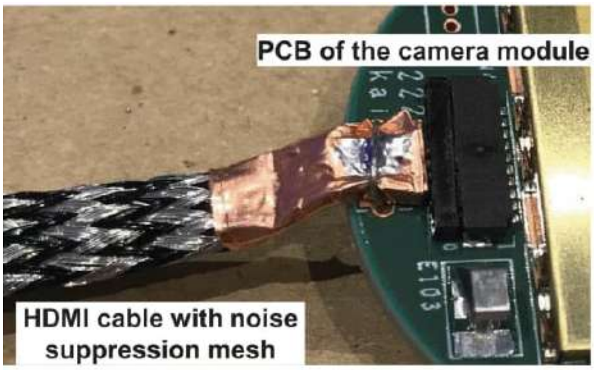

Figure 6: [1] HDMI Cable Shielding

placement was optimized to maintain distance from noisy components, minimizing direct EMI coupling into the communication system.

6. Effectiveness of Countermeasures

When all countermeasures were implemented together, EMI levels were reduced by up to 26 dB in critical frequency bands. This significantly restored receiver sensitivity and ensured stable communication links. The results confirmed that EMI can be effectively controlled through proper circuit design and structural shielding techniques.

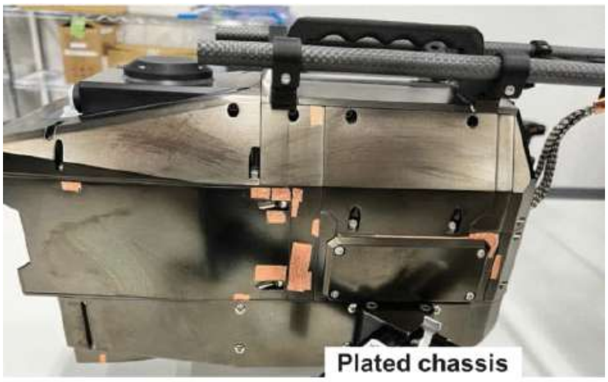

Figure 7: [1] Conductive plating for UAV chassis

7. Results and Discussion

The experimental results showed that internally generated EMI significantly degraded UAV communication performance, with a maximum sensitivity loss of about 29 dB at 800 MHz. The 1800 MHz and 2100 MHz bands also experienced noticeable degradation, confirming that self-jamming affects multiple frequency bands.After implementing countermeasures such as PCB redesign, cable shielding, DC–DC converter shielding, chassis plating, and optimized antenna placement, EMI levels were reduced by up to 26 dB. Receiver sensitivity was restored, and stable communication was achieved. These results demonstrate that EMI in UAV systems can be effectively controlled through proper engineering design and electromagnetic compatibility measures.

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ELECTRIC VEHICLE

A DATA-DRIVEN BLACK BOX MODEL FOR PREDICTING EV ENERGY CONSUMPTION

Samson Sunny
Student, S8 ECE B.Tech (2022-2026)
Vidya Academy of Science and Technology
Department of Electronics & Communication Engineering
Kerala, India

Abstract

Electric Vehicles (EVs) have become an essential solution for sustainable transportation. Yet, predicting the driving range accurately still remains a challenge because EVs operate in non-ideal and constantly changing environments. Classical models primarily rely on simplified assumptions and usually ignore realistic effects such as aggressive driving, auxiliary loads, battery degradation, and environmental variations.

This paper presents a Black Box approach that focuses on measurable inputs instead of complex physical modeling. The model integrates several key parameters such as velocity profile, acceleration pattern, terrain slope, temperature, battery condition, payload, and auxiliary load into a single estimation framework. By correlating real data with total energy consumption, the proposed method improves range estimation accuracy and supports informed decision making for drivers, manufacturers, and smart transportation systems.

Introduction

Electric Vehicles contribute significantly to reducing pollution and dependency on fossil fuels. However, range uncertainty discourages many potential users. Unlike conventional vehicles, EVs respond strongly to driving style, battery temperature, and surrounding environmental conditions.

Conventional energy models rely on physics-based equations of motion. Although accurate under laboratory conditions, they fail to capture real-world uncertainties such as frequent acceleration, stop–go traffic, or varying temperature. Therefore, there is a need for a more flexible and data-driven framework.

The Black Box approach is attractive because it:

- allows incorporation of several variables without detailed subsystem modeling,
- adapts easily to different EV platforms,
- utilizes existing vehicle sensors and controller data,
- supports real-time implementation.

This work focuses on developing such a model and demonstrating its effectiveness.

Electric Vehicle System Overview

The major subsystems interact with each other and share the available energy from the battery. Any change in one block directly influences the others, making prediction complex.

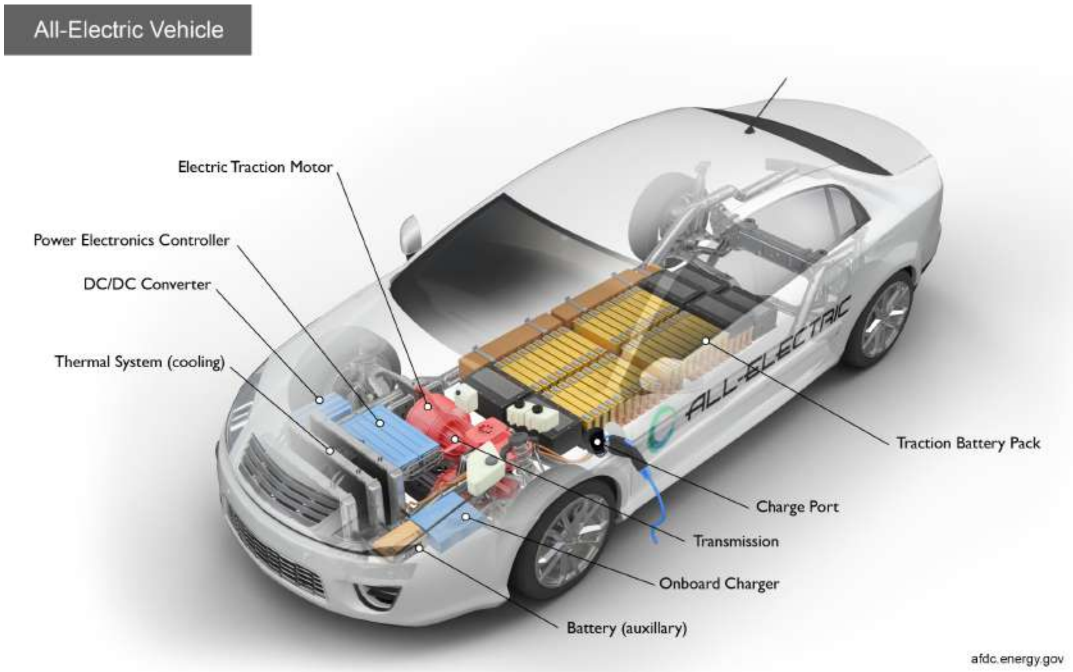

Fig. 1: Overall structure of electric vehicle system ([1]

Black Box Model Development

The development process begins with identifying realistic parameters that significantly influence energy consumption. These values are already available through BMS logs, GPS data, powertrain sensors, and environmental monitoring units.

Once identified, the parameters are grouped logically so that their combined effects can be studied without overwhelming computational cost. The framework is flexible enough to include new parameters whenever new measurement technologies become available.

The Black Box model does not try to recreate every physical equation. Instead, it learns the mapping between input variables and total consumed energy. This reduces modeling complexity while retaining accuracy.

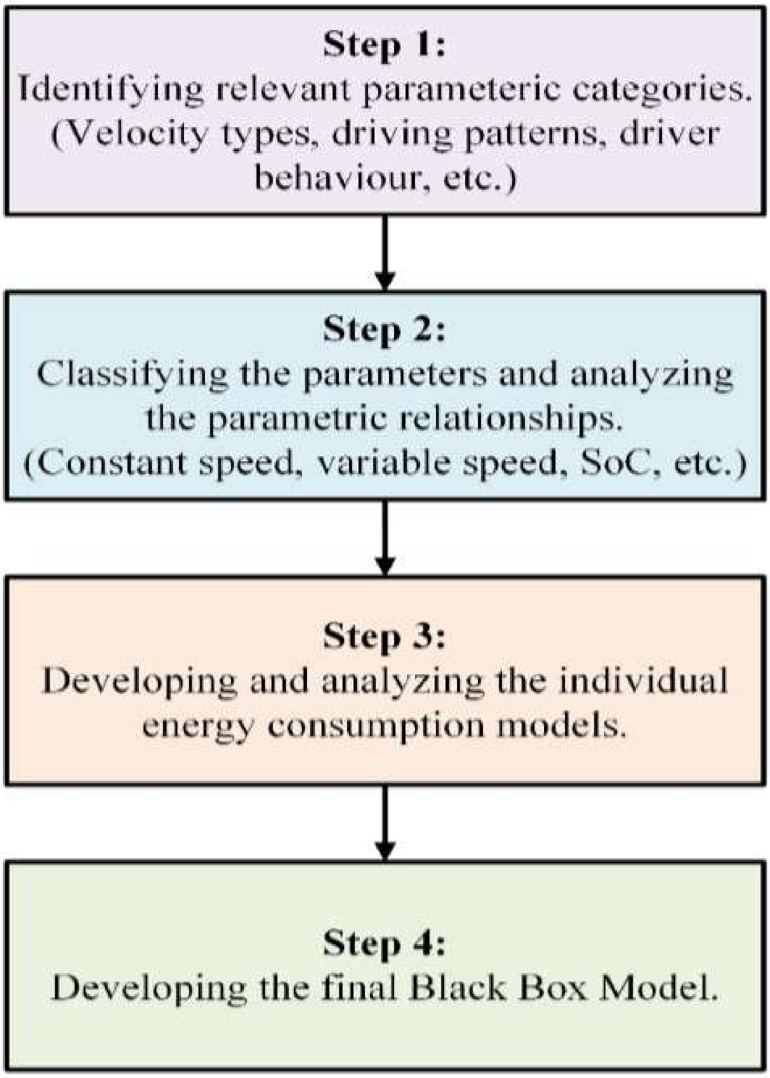

Fig. 2: Step-by-step methodology for Black Box Model development. ([2])

The modular nature of the framework makes it suitable for commercial EV platforms and research applications.

Mathematical Representation

The total energy consumed during a trip is expressed as:

$$E_{Total} = f(v, a, \theta, T_{amb}, SoC, HVAC, m_{load}, \ldots)$$

In this expression:

- v — vehicle velocity pattern,
- a — acceleration and braking activity,
- θ — gradient or slope of the road,
- T_{amb} — ambient temperature,
- SoC — state of charge,
- $HVAC$ — auxiliary load contribution,
- m_{load} — payload carried by the vehicle.

Each parameter contributes differently depending on the driving scenario. The framework aggregates their effects to estimate energy more realistically.

Key Parameters Considered

TABLE I: Representative EV Parameters

Category	Example Parameters	Source
Velocity	Average / Maximum speeds	Speed Sensor
Acceleration	Rapid braking, jerk	IMU / OBD
Battery	SoC, DoD, temperature, aging	BMS
Environment	Ambient temp., terrain	External Sensors
Auxiliary Loads	HVAC, Infotainment	EMS
Route	Traffic, distance, slope	GPS
Load	Cargo and passenger weight	Load Cells

Discussion

The proposed approach demonstrates that including previously neglected factors such as HVAC, payload weight, and thermal effects significantly enhances estimation accuracy.

Because the model is data driven, it can be retrained or tuned for different vehicles, battery capacities, and climates. It also opens possibilities for driver assistance systems that recommend eco-friendly driving patterns, and for fleet operators who wish to manage routes optimally.

Another important advantage is compatibility with artificial intelligence frameworks. Machine learning models can be layered on top of this structure to improve adaptation over time.

Conclusion

This paper discussed a Black Box based methodology for EV energy estimation. By focusing on measurable and realistic operating parameters, the model bridges the gap between ideal laboratory analysis and practical road conditions. The framework is scalable, adaptable, and suitable for future EV management systems.

Future research may involve real-time implementation, larger dataset validation, and integration with predictive AI models to create intelligent and self-learning EV platforms.

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INTERNET OF THINGS

IOT-ENABLED WATER MONITORING: A SUSTAINABLE SOLUTION FOR SMART CITIES

Jyothsna Sunil
Student, S8 ECE B.Tech (2022-26)
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

Water scarcity and inefficient water management have become serious challenges in modern urban environments. Conventional water meters are mostly analog and require manual readings, which often lead to inaccurate billing and delayed detection of water leakage. To address these issues, IoT-enabled water monitoring systems are gaining attention. This article presents a retrofit-based smart water monitoring solution that upgrades existing analog water meters using low-cost electronic components. The system employs edge computation to locally process water meter images and extract readings, reducing data transmission and power consumption. Solar energy harvesting is integrated to ensure long-term and sustainable operation. Field deployment results demonstrate high accuracy, reliability, and suitability of the system for smart city applications.

Introduction

Water is one of the most essential natural resources for human life, yet rapid urbanization and population growth have significantly increased water demand. Many cities still rely on traditional water meters that require manual readings, making real-time monitoring impossible. This often results in unnoticed leakages, water wastage, and inefficient resource utilization.

Smart Water Meters (SWMs) offer a promising solution by enabling continuous monitoring of water consumption, automated billing, and early leak detection. However, replacing existing analog meters with digital smart meters is costly and requires major infrastructure upgrades. A practical alternative is a retrofit approach, where existing meters are upgraded without replacement. This article discusses an IoT-based retrofit smart water monitoring system designed for sustainable and large-scale deployment.

System Overview

The proposed water monitoring system consists of a compact hardware module attached to an existing analog water meter. A camera captures images of the meter dial at fixed intervals. These images are processed locally using an edge computing device to extract the numerical water consumption values.

Only the processed readings are transmitted to the cloud through wireless communication, where the data is stored and visualized. A solar panel and battery power the system, allowing autonomous operation with minimal maintenance.

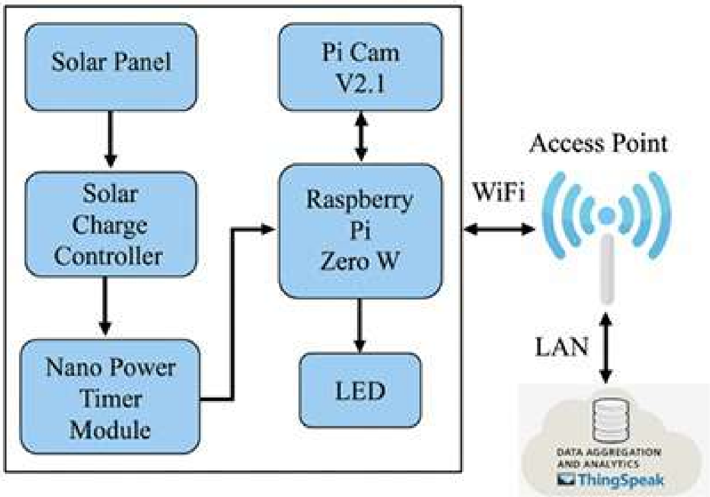

Figure 2: Block diagram of retrofit device

Fig. 1: Block diagram of IoT-enabled retrofit water monitoring system [1]

Key Components of the Proposed System

The major components of the system include:

- **Retrofit Smart Meter Module:** Enables upgrading of existing analog meters without replacement.
- **Edge Computing Unit:** A Raspberry Pi Zero W processes meter images locally.
- **Camera Module:** Captures periodic images of the meter display.
- **Wireless Communication:** Transfers processed data to the cloud using Wi-Fi.
- **Solar Energy Harvesting Unit:** Provides sustainable power using a solar panel and battery backup.

This combination ensures low cost, scalability, and long-term deployment.

Edge Computation and Data Processing

Edge computation plays a key role in improving system efficiency. Instead of sending raw images to the cloud, image processing and digit recognition are performed locally. The captured image undergoes preprocessing steps such as grayscale conversion, noise filtering, and region-of-interest extraction.

Machine learning techniques are then applied to recognize the meter digits accurately. Only the final numerical readings are transmitted to the cloud, significantly reducing bandwidth usage and power consumption.

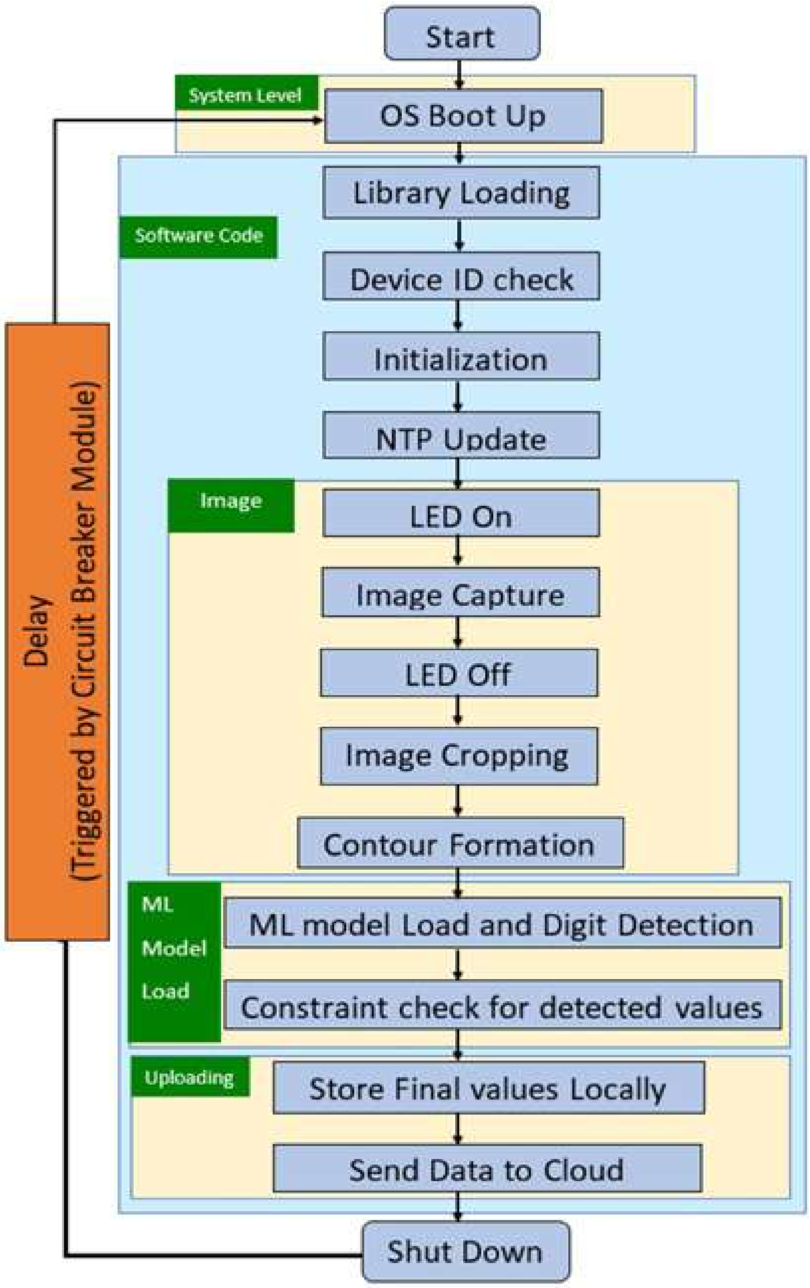

Fig. 2: Edge computation workflow for water meter reading extraction [1]

Energy Harvesting and Power Optimization

Power efficiency is critical for outdoor IoT deployments. The system uses multiple optimization techniques, such as disabling unused peripherals, reducing boot-up time, and utilizing a nano power timer to minimize idle current.

Solar energy harvesting continuously recharges the battery, ensuring uninterrupted operation even in remote locations. This approach reduces maintenance costs and promotes eco-friendly energy usage.

Field Deployment and Results

The system was deployed across a university campus covering more than 25 water meters installed in hostels, academic buildings, and residential areas. The deployment tested the system under different flow rates and environmental conditions.

The results showed:

- 97.7% accuracy in digit recognition.
- Reliable operation over several months.
- Significant reduction in data transmission size.
- Effective battery lifetime of nearly 6 years with solar support.

These results validate the practicality and robustness of the proposed solution.

Applications of Smart Water Monitoring

The proposed system can be effectively used in:

- Smart city water management
- Leak detection and water conservation
- Automated billing systems
- Consumer awareness and usage analytics
- Sustainable urban infrastructure

Challenges

Despite its advantages, the system faces certain challenges:

- Dependence on wireless network availability
- Sensitivity to lighting conditions for camera-based sensing
- Initial calibration during installation

Ongoing research aims to overcome these limitations.

Future Prospects and Conclusion

Future improvements include integration of long-range communication technologies such as LoRa, enhanced security mechanisms, and AI-based anomaly detection. With continuous advancements, retrofit smart water meters can become a core component of smart city infrastructure.

In conclusion, IoT-enabled retrofit water monitoring systems provide a low-cost, energy-efficient, and sustainable solution for modern water management. By combining edge computation and solar energy harvesting, the system offers high accuracy, long operational life, and minimal maintenance, making it ideal for large-scale deployment.

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HARDWARE EVALUATION OF A CLUSTER-BASED AGRICULTURE IoT MONITORING SYSTEM

Gayathri P A

Student, S8 ECE B.Tech (2022-26)

Vidya Academy of Science and Technology

Department of Electronics & Communication Engineering

P.O. Thalakkottukara, Kerala

Abstract

Smart agriculture relies heavily on reliable sensing and efficient communication among field-deployed devices. However, many agricultural IoT solutions remain limited to simulations and lack real-world validation. This paper presents a practical hardware evaluation of a cluster-based agricultural IoT system designed for field monitoring applications. The proposed setup uses low-power sensor nodes grouped into clusters to reduce communication overhead and improve energy efficiency. Hardware components such as microcontrollers, environmental sensors, and wireless modules are integrated and tested under realistic conditions. The evaluation focuses on system reliability, power usage, and data transmission performance. The results demonstrate that cluster-based architectures are well-suited for agricultural IoT deployments where simplicity, scalability, and energy efficiency are critical.

Introduction

Agriculture is increasingly adopting Internet of Things (IoT) technologies to improve productivity, reduce resource wastage, and enable data-driven decision making. Sensors deployed across farmland can continuously monitor parameters such as soil moisture, temperature, and humidity. However, deploying large numbers of sensor nodes introduces challenges related to power consumption, communication reliability, and system scalability.

Traditional centralized IoT architectures often require each sensor node to transmit data directly to a base station, resulting in high energy usage and reduced network lifetime. To address this issue, cluster-based network architectures group nearby sensor nodes and assign a cluster head to manage communication. This approach significantly reduces redundant transmissions and balances network load.

Cluster-Based IoT System Overview

In a cluster-based IoT network, sensor nodes are organized into small groups known as clusters. Each cluster contains multiple member nodes and a single cluster head. The member nodes collect environmental data and forward it to the cluster head. The cluster head aggregates this data and transmits it to a base station or gateway.

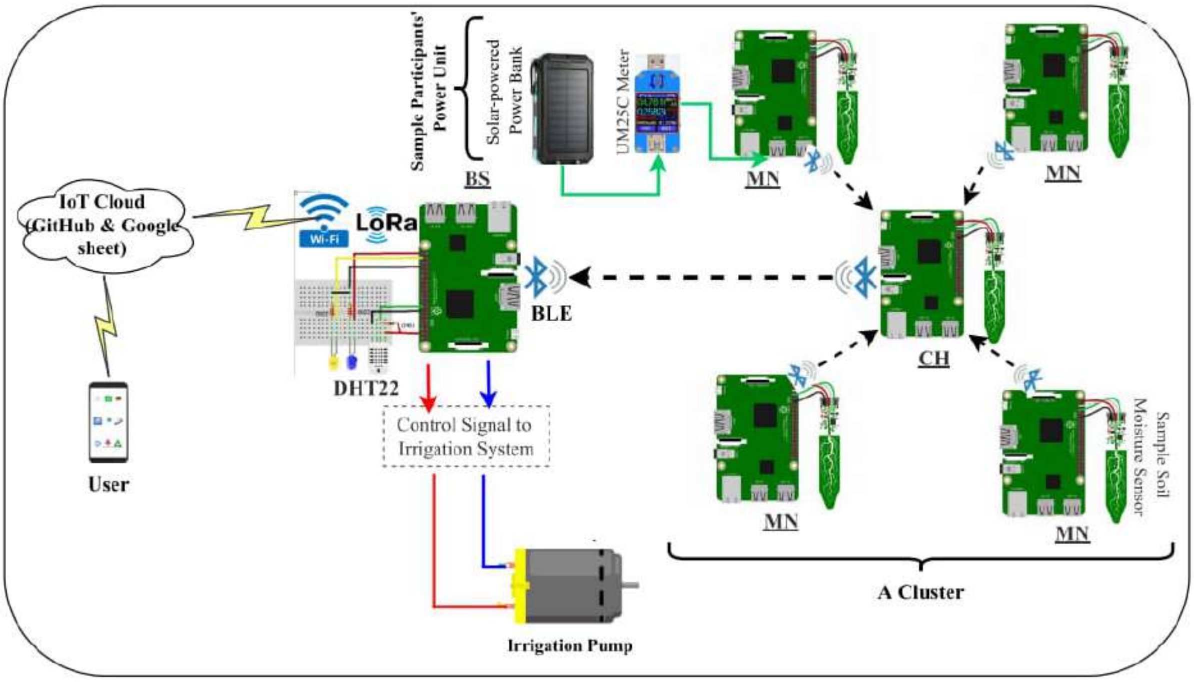

Fig. 1: Schematic diagram of CA-IoT system [1].

This structure minimizes long-distance communication by low-power nodes and limits high-energy transmissions to a smaller number of cluster heads. As a result, overall energy consumption is reduced, and the system becomes more scalable for large agricultural fields.

Hardware Architecture

The proposed system consists of three main hardware entities:

- **Sensor Nodes:**
  Sensor nodes are responsible for data acquisition. Each node integrates environmental sensors such as soil moisture sensors and temperature-humidity sensors. A low-power microcontroller processes the sensed data and communicates with the cluster head using short-range wireless communication.
- **Cluster Head:**
  The cluster head performs dual roles. It acts as a sensing node while also receiving data from nearby member nodes. The cluster head aggregates the collected information, filters redundant data, and forwards meaningful readings to the base station. Due to its increased workload, the cluster head is equipped with higher processing capability and a more reliable power source.
- **Base Station:**
  The base station serves as the central data collection point. It receives aggregated data from cluster heads and stores it locally or forwards it to a cloud platform for visualization and analysis. The base station can also support control actions such as triggering irrigation systems based on received sensor values.

Working Principle

The system operates in a cyclic manner. Sensor nodes periodically sense environmental parameters and transmit the data to their respective cluster heads. The cluster heads perform basic data aggregation and error checking before forwarding the processed data to the base station.

By limiting long-range transmissions to cluster heads only, the network conserves energy and reduces channel congestion. This operating principle is especially effective in agricultural environments where sensor nodes are deployed over wide areas and are expected to operate for long durations without frequent maintenance.

Applications

The proposed cluster-based agricultural IoT system can be applied in:

- Precision irrigation systems
- Soil health monitoring
- Greenhouse automation
- Crop growth analysis
- Remote farm monitoring

Advantages

- Reduced power consumption
- Improved network scalability
- Reliable data transmission
- Simple and modular hardware design
- Suitable for large agricultural fields

Conclusion

This paper presented a practical hardware evaluation of a cluster-based agricultural IoT monitoring system. By organizing sensor nodes into clusters and assigning dedicated cluster heads, the system achieves improved energy efficiency and communication reliability. The hardware results confirm that cluster-based architectures are a practical choice for agricultural IoT deployments. Future work may include integrating cloud analytics and intelligent decision-making algorithms to further enhance system functionality.

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HUFFMAN DEEP COMPRESSION OF EDGE NODE DATA FOR REDUCING IOT NETWORK TRAFFIC

Riya N R
Student, S8 ECE B.Tech (2022-26)
Vidya Academy of Science and Technology
Department of Electronics & Communication Engineering
P.O. Thalakkottukara, Kerala

Abstract

The rapid growth of Internet of Things (IoT) devices in smart cities has resulted in massive data generation from sensors. Continuous transmission of this data increases network traffic, memory usage, and power consumption at IoT edge nodes. Traditional compression algorithms such as Huffman Coding and LZW are not fully suitable for memory-constrained IoT devices. To address these challenges, Huffman Deep Compression (HDC) is introduced as an advanced lossless compression technique. The proposed method combines sliding window segmentation, pattern-based matching, pruning, and pooling techniques inspired by deep learning. This approach reduces memory usage, decreases network traffic, and achieves higher compression ratios while maintaining data accuracy. Experimental analysis shows that HDC can reduce data size by nearly 60% while operating within 80KB memory limits, making it highly suitable for smart city IoT applications.

Introduction

Smart cities depend heavily on IoT devices such as air pollution sensors, smart meters, traffic monitors, and environmental monitoring systems. These devices continuously generate large volumes of time-series data.

However, IoT edge nodes typically have:

- Limited RAM (around 80KB)
- Limited processing power
- Energy constraints

When raw sensor data is transmitted directly to the cloud, it causes:

- Heavy network traffic
- Increased energy consumption
- Memory overflow risks

Data compression is an effective solution to reduce this burden. Traditional algorithms like the Huffman Coding Algorithm (HCA) provide lossless compression, but they require large memory to build Huffman trees. Therefore, a modified and optimized version called Huffman Deep Compression (HDC) is proposed to fit within IoT memory constraints.

System Overview

The Huffman Deep Compression system operates at the IoT edge node before data transmission.

The process includes:

- Collecting sensor data

- Segmenting data using a sliding window
- Identifying repeated patterns
- Calculating pattern weights
- Constructing optimized Huffman trees
- Applying pruning and pooling techniques
- Transmitting compressed data to the cloud

This approach ensures that only compressed and optimized data is sent, reducing traffic and power usage.

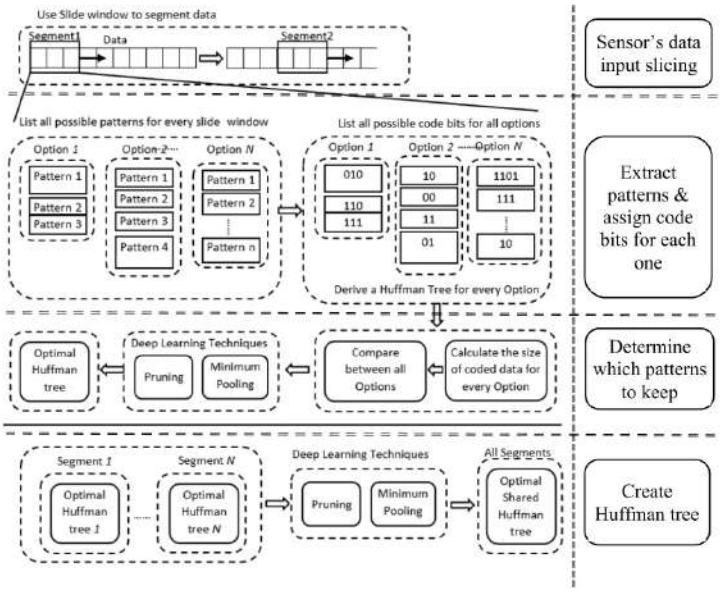

Fig. 1: Proposed Huffman compression steps [1].

KEY COMPONENTS OF THE PROPOSED SYSTEM

The major components of HDC include:

- **Sliding Window Segmentation:** Divides large sensor data into smaller segments that fit into IoT memory.
- **Pattern-Based Matching:** Instead of matching individual symbols, repeated data patterns are identified.
- **Weight Calculation:** Pattern weight is calculated using

$$Weight = Frequency \times Pattern\ Size$$

- **Optimized Huffman Tree:** Shorter codewords are assigned to patterns with higher weights.
- **Pruning Technique:** Removes redundant and repeated codewords across different segments.
- **Pooling Technique:** Selects minimum-length codewords to reduce tree complexity.

This combination significantly reduces memory usage and improves compression efficiency.

EDGE COMPUTATION AND MEMORY OPTIMIZATION

Traditional Huffman coding constructs a large tree using symbol frequency. In IoT systems, this leads to:

- High memory consumption
- Increased SRAM usage

- Processing delay

HDC solves this by:

- Processing only small data segments at a time
- Sharing optimized Huffman trees across segments
- Removing unnecessary patterns
- Using pattern weights instead of symbol frequency

Experimental results show that HDC operates within:

- Less than 80KB RAM
- Current consumption below 45 mAmps during compression

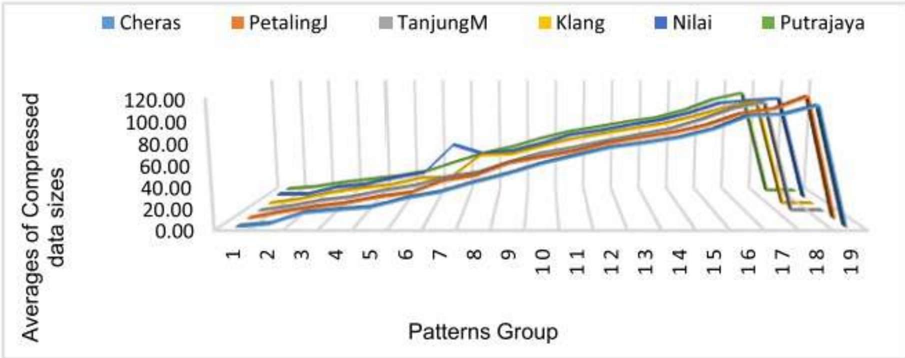

Fig. 2: Correlation between compressed data size and pattern number for city datasets [2].

Experimental Results

The HDC algorithm was tested using time-series sensor datasets from multiple monitoring stations.
Results showed:

- Data size reduction: 58% – 60%
- Compression Ratio (CR): Approximately 2.6
- Memory usage: Less than 80KB
- Lower network traffic compared to AH and LZW algorithms
- Statistical significance ($p < 0.0005$) when compared with traditional methods

The results confirm that HDC performs better than Adaptive Huffman (AH) and LZW compression techniques for IoT environments.

Applications of Huffman Deep Compression

HDC can be applied in:

- Smart city sensor networks
- Environmental monitoring systems
- Smart water and energy meters
- Healthcare IoT devices
- Industrial IoT systems
- Wireless Sensor Networks (WSN)

Challenges

Despite its advantages, HDC faces certain challenges:

- Complexity in pattern extraction
- Implementation difficulty on very low-end microcontrollers
- Optimization required for real-time systems
- Scalability for extremely large sensor networks

Future Prospects and Conclusion

Future improvements of HDC may include:

- Integration with LoRaWAN communication
- Hardware-level compression implementation
- AI-based adaptive sliding window selection
- Improved security with encrypted compression

In conclusion, Huffman Deep Compression provides a powerful and memory-efficient solution for IoT edge devices. By combining sliding window techniques with deep learning-inspired pruning and pooling, HDC reduces network traffic by nearly 60% while operating within strict IoT memory constraints. This makes it an ideal compression method for smart city applications.

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LORAWAN AND LPWAN TECHNOLOGIES: POWERING THE NEXT BILLION IoT DEVICES

Anjali Sunil
Student, S6 ECE B.Tech (2023–27)
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

The rapid growth of the Internet of Things (IoT) has created a strong demand for wireless communication technologies that are long-range, energy-efficient, and cost-effective. Traditional wireless systems such as Wi-Fi and cellular networks are often unsuitable for large-scale IoT deployments due to high power consumption and operational costs. This has led to the emergence of Low Power Wide Area Network (LPWAN) technologies, among which LoRaWAN has gained significant attention.

LoRaWAN enables long-distance communication with ultra-low power consumption, allowing battery-powered devices to operate for several years. It is designed to support massive numbers of IoT nodes while maintaining reliable data transmission over wide geographic areas. These features make LoRaWAN ideal for applications such as smart cities, environmental monitoring, agriculture, industrial automation, and remote asset tracking.

This paper discusses the fundamentals of LPWAN technologies with a focus on LoRaWAN architecture, working principles, advantages, and real-world applications. It also highlights the role of LoRaWAN in enabling scalable and sustainable wireless communication for the rapidly expanding IoT ecosystem.

Introduction

The Internet of Things (IoT) is transforming the modern world by connecting billions of devices such as sensors, smart meters, healthcare devices, and industrial equipment. As the number of connected devices increases, traditional wireless technologies such as Wi-Fi, Bluetooth, and cellular networks face challenges related to energy consumption, cost, and coverage.

Low Power Wide Area Networks (LPWAN) have emerged as a solution to address these challenges. LPWAN technologies are designed to provide long-range communication while consuming extremely low power. Among the various LPWAN solutions, LoRaWAN has gained significant popularity due to its scalability, reliability, and cost efficiency. These technologies are expected to play a critical role in supporting the next generation of IoT systems.

Low Power Wide Area Network (LPWAN)

LPWAN is a class of wireless communication technologies specifically designed for IoT applications requiring long-range connectivity and minimal power consumption.

The key characteristics of LPWAN include:

- Very low power consumption allowing devices to operate for 5–10 years on battery
- Long communication range up to 15–20 km in rural areas
- Low data transmission rates suitable for sensor data
- Low deployment and operational cost

Some of the popular LPWAN technologies include:

- LoRaWAN
- NB-IoT (Narrowband IoT)
- LTE-M (Cat-M1)
- Sigfox

LoRaWAN Technology

LoRaWAN (Long Range Wide Area Network) is a communication protocol designed for large-scale IoT networks. It is built on LoRa radio modulation technology and standardized by the LoRa Alliance.

LoRaWAN operates in unlicensed ISM frequency bands such as 868 MHz in Europe and 865–867 MHz in India. It provides secure and long-distance communication between devices and network infrastructure.

Fig. 1: Architecture of LoRaWAN network [2]

Working of LoRaWAN

LoRaWAN follows a star-of-stars network topology consisting of the following components:

- **End Devices:** Sensors or actuators that collect environmental data.
- **Gateways:** Receive data from end devices and forward it to the network server.
- **Network Server:** Handles routing, authentication, and network management.
- **Application Server:** Processes data and provides services to end users.

This architecture enables scalable and efficient communication for large numbers of IoT devices.

Fig. 2: Different LPWAN technologies used in IoT systems [1]

Advantages of LoRaWAN

LoRaWAN provides several advantages for IoT communication systems:

- Ultra-low power consumption
- Long-range wireless communication
- High scalability supporting thousands of devices
- Cost-effective deployment
- Strong security using AES-128 encryption

Applications of LoRaWAN

LoRaWAN is widely used across different sectors due to its energy efficiency and long-range communication capability.

- **Smart Cities:** Smart lighting, waste management, and parking systems
- **Smart Agriculture:** Soil monitoring, irrigation control, and livestock tracking
- **Industrial IoT:** Asset tracking and predictive maintenance
- **Healthcare:** Remote patient monitoring and wearable sensors
- **Utilities:** Smart electricity, gas, and water metering

Challenges of LPWAN and LoRaWAN

Despite its advantages, LPWAN technologies face several limitations:

- Low data rates compared to other wireless technologies
- Higher communication latency
- Duty-cycle restrictions in unlicensed frequency bands
- Possible interference in crowded ISM spectrum

Future of LPWAN and LoRaWAN

The future of LPWAN technologies is promising as they continue to evolve alongside emerging communication technologies. Integration with 5G networks, satellite-based LoRaWAN connectivity, and improved adaptive data rate mechanisms are expected to further enhance network performance.

These advancements will enable widespread IoT adoption in smart cities, agriculture, environmental monitoring, and industrial automation.

Conclusion

LoRaWAN and LPWAN technologies are transforming the IoT communication landscape by offering long-range, energy-efficient, and cost-effective connectivity solutions. As the number of connected devices continues to grow, these technologies will play a crucial role in enabling scalable IoT networks worldwide. Their ability to support massive device connectivity while maintaining low power consumption makes them ideal for future smart infrastructure and digital ecosystems.

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NETWORK AND SECURITY

REAL-TIME MONITORING OF COMMUNICATION PROTOCOLS IN 6G MOBILE NETWORK CONSUMER APPLICATIONS

Nikhitha Joy
Student, S8 ECE B.Tech (2022-26)
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

The rapid evolution of wireless communication has led to the development of sixth-generation (6G) mobile networks, which aim to provide ultra-high data rates, ultra-low latency, and massive connectivity. With the increasing number of consumer devices and Internet of Things (IoT) applications, efficient monitoring and management of communication protocols have become essential. This article discusses real-time monitoring of communication protocols in 6G mobile networks, highlighting the role of Reconfigurable Intelligent Surfaces (RIS), Dynamic Channel Allocation (DCA), and intelligent resource management. The integration of these technologies improves spectral efficiency, reduces interference, and enhances network reliability. The article also presents applications, challenges, and future prospects of real-time protocol monitoring in 6G consumer network environments.

Introduction

Wireless communication systems have evolved from 1G to 5G, enabling significant improvements in speed, connectivity, and user experience. However, emerging applications such as augmented reality, autonomous systems, smart homes, and massive IoT demand even higher performance and reliability. To address these requirements, 6G mobile networks are being developed with a focus on intelligent, adaptive, and energy-efficient communication.

In 6G networks, real-time monitoring of communication protocols plays a crucial role in ensuring seamless data transmission. Dense user deployment, heterogeneous devices, and dynamic traffic patterns introduce severe interference and resource management challenges. Traditional static allocation methods are insufficient in such environments. Therefore, advanced techniques such as Reconfigurable Intelligent Surfaces (RIS) and Dynamic Channel Allocation (DCA) are integrated to enable real-time adaptation and optimized network performance.

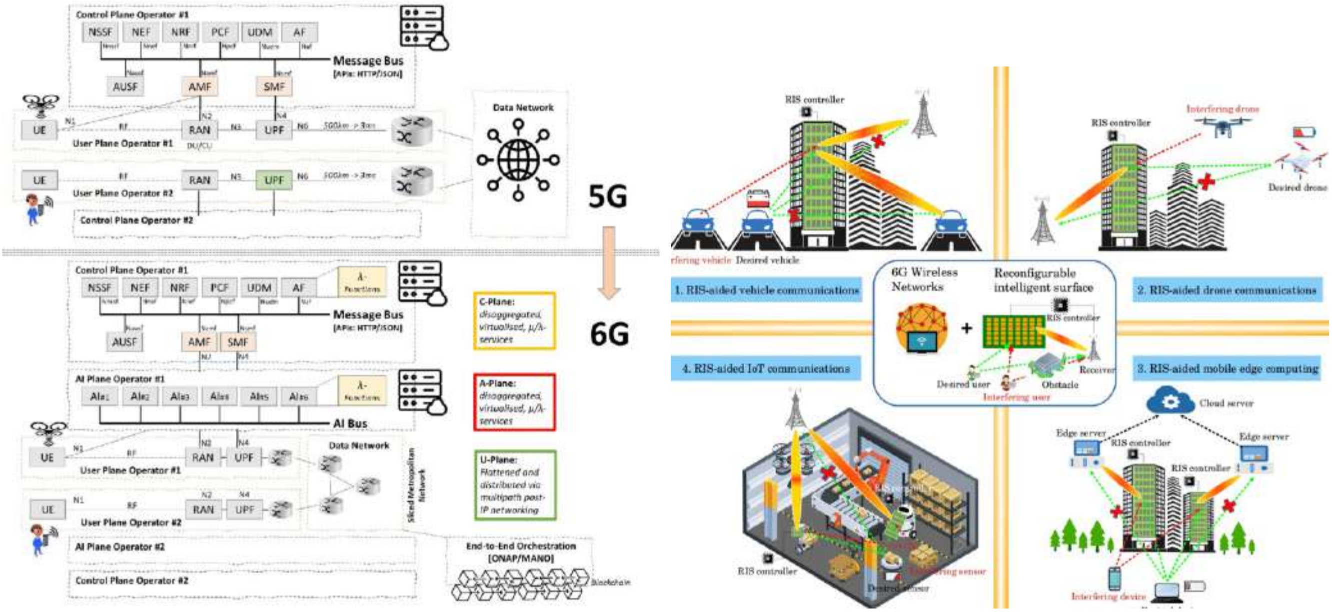

Fig. 1: Architecture of a 6G mobile network with real-time monitoring [1].

Key Technologies in Real-Time 6G Monitoring

Real-time monitoring in 6G networks relies on several enabling technologies:

- **Reconfigurable Intelligent Surfaces (RIS):** RIS are programmable surfaces that control the propagation of electromagnetic waves. By adjusting phase shifts dynamically, RIS enhance signal strength and suppress interference.
- **Dynamic Channel Allocation (DCA):** DCA assigns frequency and power resources based on real-time channel conditions, traffic load, and interference levels, improving spectral efficiency.
- **Non-Orthogonal Multiple Access (NOMA):** NOMA allows multiple users to share the same frequency band using power-domain multiplexing, increasing network capacity.
- **IoT-Based Monitoring:** IoT sensors continuously collect network data such as latency, traffic, and interference, enabling intelligent decision-making and adaptive control.

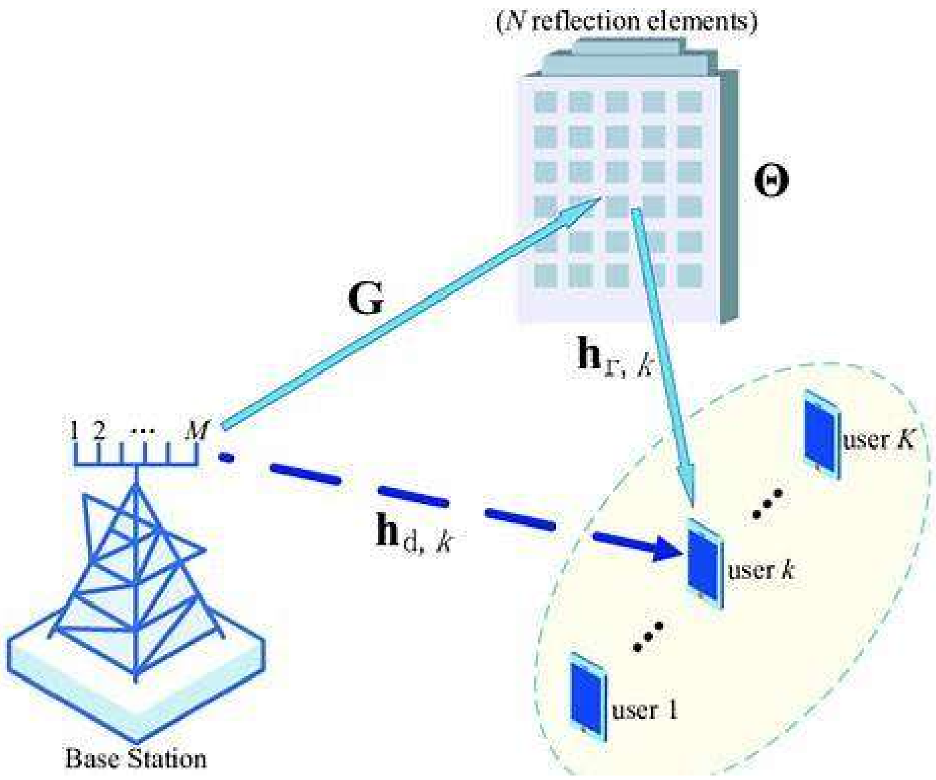

Fig. 2: RIS-assisted signal reflection and interference mitigation in 6G networks [2].

Applications in Consumer Networks

Real-time monitoring of communication protocols in 6G enables several consumer-oriented applications:

- **Smart Homes and IoT Systems:** Ensures reliable and low-latency communication between connected devices.
- **Augmented and Virtual Reality (AR/VR):** Supports ultra-low latency and high data rates required for immersive experiences.
- **Autonomous Vehicles:** Enables real-time data exchange for navigation, safety, and traffic management.
- **High-Speed Mobile Broadband:** Provides seamless connectivity for next-generation consumer electronics.

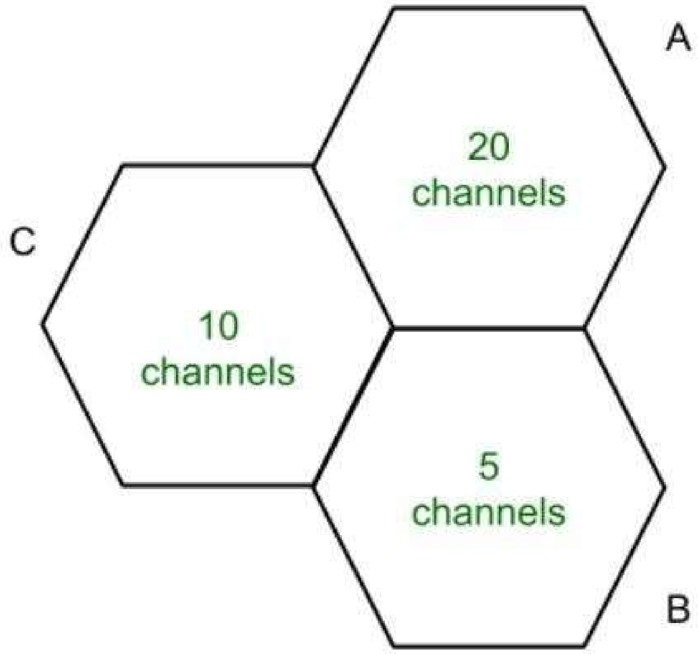

Fig. 3: Real-time monitoring and dynamic channel allocation process in 6G networks [3].

Challenges

Despite its advantages, real-time monitoring in 6G networks faces several challenges:

- **High System Complexity:** Integration of RIS, DCA, and intelligent monitoring increases computational complexity.
- **Hardware Cost:** Large-scale deployment of RIS and advanced sensors requires significant investment.
- **Environmental Sensitivity:** Wireless signals and intelligent surfaces are affected by dynamic environments and mobility.
- **Scalability Issues:** Maintaining real-time performance in ultra-dense networks remains a challenge.

Future Prospects and Conclusion

Real-time monitoring of communication protocols is a key enabler for efficient and reliable 6G mobile networks. The integration of RIS, DCA, NOMA, and IoT-based intelligence enables adaptive communication, improved spectral efficiency, and reduced interference. As research progresses, advancements in artificial intelligence and energy-efficient hardware will further enhance real-time monitoring capabilities.

In conclusion, real-time protocol monitoring will play a vital role in supporting future 6G consumer applications, ensuring high reliability, low latency, and intelligent network operation.

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RENEWABLE ENERGY

SUSTAINABLE DEVELOPMENT GOALS (SDGs)

Dr. S. Swapna Kumar
Professor and Head, Dept. of ECE
Vidya Academy of Science and Technology
Department of Electronics and Communication Engineering
Kerala, India

Sustainable Development Goals

The Sustainable Development Goals (SDGs) were created by the United Nations (UN) in 2015 as part of the 2030 Agenda. This framework includes 17 international objectives aimed at tackling challenges such as poverty, inequality, climate change, and environmental concerns. Core principle of the UN SDGs is:

"Leave no one behind."

Fig. 1: Sustainable Development Goals framework introduced by the United Nations [1].

This highlights that everyone, regardless of gender, age, place, country, ability, or socioeconomic status, should avail from global advancement. Building on the Millennium Development Goals (MDGs) of 2000–2015, the SDGs emphasize a comprehensive method to promote prosperity for population and the planet. Engineers in disciplines like Electronics and Communication Engineering (ECE) can use technologies like IoT, AI, 5G, and sensors to formulate practical effects thanks to these goals. In order to promote technological adoption in a quickly evolving digital environment, this paper explores the fundamental ideas of the SDGs and the crucial contributions of ECE, outlining workable project scopes.

These goals are linked together and offer a complete structure for obtaining well-being for individuals and nature.

Evolution Timeline (Related Milestones):

In 1972 the Stockholm Conference on the Human Environment marks the start of global consciousness regarding viable growth.
In 1987, the Brundtland Commission defined viable development as meeting for future development.
In 1992 the Agenda 21 was launched during the Earth Summit in Rio.
In 2000 the MDGs developed eight objectives.
In 2015 create a change to 17 SDGs that address social, economic, and environmental aspects.

Problem behind creating the 17 SDGs

The 17 SDGs (2015) were introduced to overcome gaps in the MDGs (2000–2015) by tackling the root causes of environmental degradation, unsustainable growth, and inequality in order to balance progress for people and the earth.

Fig. 2: The 17 Sustainable Development Goals addressing global social, economic and environmental challenges [2].

The 17 SDGs, which were created in 2015 in response to current world issues, are shown in the infographic. With each related to particular goals, they are divided into three categories: Social, Economic, and Environmental.
1. Social Issues: Poverty, inequality, health, education.
2. Economic Concerns: Unemployment, lack of creativity, and unsustainable expansion.
3. Environmental Challenges: biodiversity loss, pollution, and climate change.

1. Social Issues:

These focus on human well-being, equality, and access to basic needs.

Problem	Description	Related SDGs
Global hunger and poverty	Millions of people lack money, food, and shelter.	SDG 1 – No Poverty, SDG 2 – Zero Hunger
Poor health and well-being	Illnesses, poor hygienic practices, and a lack of medical facilities.	SDG 3 – Good Health and Well-being
Unequal access to education	Unequal access to digital education and education.	SDG 4 – Quality Education, SDG 5 – Gender Equality
Lack of energy and water.	In rural areas, there is a lack of affordable energy and clean water.	SDG 6 – Clean Water and Sanitation SDG 7 – Affordable and Clean Energy

TABLE I: Social problems, their description, and related SDGs

2. Economic Issues:
These relate to jobs, technology, innovation, and fair economic growth.

Problem	Description	Related SDGs
Unemployment & Lack of Innovation	Limited employment opportunities and industrial growth.	SDG 8 – Decent Work and Economic Growth, SDG 9 – Industry, Innovation, and Infrastructure
Increasing Inequalities	The digital divide and income inequality.	SDG 10 – Reduced Inequalities
Unplanned Urbanization	Congestion and pollution are caused by unchecked urban growth.	SDG 11 – Sustainable Cities and Communities
Overconsumption & Resource Waste	Overuse of resources and unsustainable industrial production.	SDG 12 – Responsible Consumption and Production

TABLE II: Economic issues, descriptions, and related SDGs

3. Environmental Issues:
These address climate change, ecosystem degradation, and resource protection.

Problem	Description	Related SDGs
Pollution and climate change	Global warming, CO2 emissions, and deforestation.	SDG 13 – Climate Action
Loss of land and marine ecosystems	Biodiversity loss, deforestation, and ocean pollution.	SDG 14 – Life Below Water, SDG 15 – Life on Land
Conflicts, Corruption, and weakened Institutions	Implementing long-term policies and difficulties to implement peace and governance.	SDG 16 – Peace, Justice, and Strong Institutions
A lack of global partnerships	Cross-national and sectoral cooperation.	SDG 17 – Partnerships for the Goals

TABLE III: Environmental challenges, descriptions, and related SDGs

Role of Electronics and Communication Engineering (ECE) in the 17 SDGs

Electronic and communication engineering (ECE) can help achieve all 17 SDGs by leveraging digital connection, automation, and smart systems.

Fig. 3: IoT applications supporting Sustainable Development Goals [3].

The figure shows how IoT applications in areas like energy, transport, health, industry, and water management connect to and support the UN Sustainable Development Goals (SDGs). It highlights that IoT acts as a central technology that drives efficiency, sustainability, and data-based improvements across multiple SDG targets.

Following are the goal-wise mapping of ECE's contributions:

1. No Poverty

ECE Role: In rural areas, access to digital and financial services is made possible by IoT-based communication.

Project Scope: To encourage financial inclusion, create a low-cost mobile Internet of Things system for digital banking and microfinance in isolated villages.

2. Zero Hunger

ECE Role: Sensors and WSN improve irrigation and crop growth.

Project Scope: Develop a real-time smart agriculture platform to maintain crops and moisture using cloud-based analytics and soil sensors.

3. Good Health and Well-being

ECE Role: Remote health monitoring is made possible by biomedical electronics.

Project Scope: Design a wearable health monitoring system integrated with cloud IoT for patient tracking and early disease detection.

4. Quality Education

ECE Role: Virtual labs and e-learning are made possible by communication networks.

Project Scope: Using a Raspberry Pi and offline e-content delivery, develop a low-bandwidth digital learning kit for rural schools.

5. Gender Equality

ECE Role: The role to access education and entrepreneurship is setup by ICT tools.

Project Scope: Create a platform for online mentoring and digital literacy to promote women in STEM and entrepreneurship.

6. Clean Water and Sanitation

ECE Role: IoT systems monitor water quality and flow control.

Project Scope: Create an automated Internet of Things water management technique that uses WSN to monitor pH, turbidity, and leak detection.

7. Affordable and Clean Energy

ECE Role: Intelligent power systems and effective energy converters enhance the use of renewable resources.

Project Scope: Implement integrated electronics to create a solar-driven microgrid manager for providing electricity in rural areas.

8. Decent Work and Economic Growth

ECE Role: Robotics and automation enhance productivity.

Project Scope: Implement an AI-based system for monitoring industrial processes to improve maintenance forecasts and energy efficiency.

9. Industry, Innovation, and Infrastructure

ECE Role: IoT, AI, and 5G technology facilitate intelligent industries.

Project Scope: Leverage industrial IoT to create a prototype for smart manufacturing aimed at automated quality assurance.

10. Reduced Inequalities

ECE Role: Digital gaps are filled by reasonably priced communication systems.

Project Scope: Create an e-governance portal and community Wi-Fi to link low-income and remote communities.

11. Sustainable Cities and Communities

ECE Role: Smart sensors aid in enhancing traffic, waste management, and safety measures.

Project Scope: Create an Internet of Things control panel that displays live data on traffic, waste, and air quality for modern cities.

12. Responsible Consumption and Production

ECE Role: Industrial processes are optimized by embedded systems.

Project Scope: Create a sensor-based production efficiency tracker that lowers factory power and material waste.

13. Climate Action

ECE Role: Sensors and AI models track environmental conditions.

Project Scope: Develop a WSN-based air pollution and CO_2 tracking network with data analytics for emission reduction policies.

14. Life Below Water

ECE Role: Underwater sensing and communication systems are used to keep an eye on marine environments.

Project Scope: Develop a sensing unit for underwater use that incorporates Internet of Things technology to monitor marine life and water conditions.

15. Life on Land

ECE Role: Deforestation and wildlife are monitored by wireless networks.

Project Scope: Develop a surveillance system with IoT and unmanned aerial vehicles to evaluate the danger of fires and illegal logging operations.

16. Peace, Justice, and Strong Institutions

ECE Role: The use of blockchain and secure communication improves openness.

Project Scope: Create a data integrity framework based on blockchain for verifying digital identities and facilitating government operations.

17. Partnerships for the Goals

ECE Role: Global communication technologies foster collaboration.

Project Scope: Develop a cloud-based international research collaboration platform using satellite and IoT data integration.

Summary Table

Aspect	**Advantages**	**Disadvantages**
Scope	Comprehensive coverage of global issues	Too broad and difficult to measure
Equity	Promotes inclusion and gender equality	Unequal progress across regions
Technology	Encourages innovation and green energy	Technological divide remains
Policy	Guides government and institutional strategies	Depends heavily on political will
Monitoring	Improves accountability and data use	Lacks standardized global metrics
Partnerships	Strengthens global collaboration	Coordination challenges between sectors

TABLE IV: Advantages and disadvantages related to SDGs

Conclusion

The SDGs were introduced by the UN in 2015 as a global framework to direct the accomplishment of 17 interrelated goals that address social, economic, and environmental issues through creative thinking and international cooperation. ECE is particularly important because it makes it possible to create intelligent, safe, and energy-efficient systems. Sustained technological advancement and cooperation will build a stronger future beyond 2030.

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PLANT MICROBIAL FUEL CELLS : A SUSTAINABLE POWER SOURCE FOR SMART AGRICULTURE

Neha Dileep
Student, S8 ECE B.Tech
Vidya Academy of Science and Technology,
Department of Electronics & Communication Engineering,
P.O. Thalakkottukara, Kerala

Abstract

Plant Microbial Fuel Cells (PMFCs) are bio-electrochemical systems that generate electrical energy by utilizing natural interactions between plant roots and soil microorganisms [1]. With the increasing deployment of sensor-based monitoring systems in agriculture, the need for sustainable and low-maintenance power sources has become critical. Conventional batteries suffer from limited lifespan, frequent replacement, and environmental concerns. PMFCs provide an eco-friendly alternative by continuously harvesting low-level electrical energy from living plants without disturbing soil health or plant growth.

This paper presents an overview of PMFC technology, including its working principle, energy harvesting capability, and its role as a self-powered biosensing platform. The integration of PMFCs with low-power wireless Internet of Things (IoT) systems for smart agriculture applications is also discussed [2].

Introduction

The adoption of smart technologies in agriculture has enabled efficient monitoring of soil conditions, crop health, and environmental parameters. Sensors deployed for measuring soil moisture, temperature, nutrient levels, and plant health require a reliable power source for long-term operation. Battery-powered systems face limitations such as periodic replacement, maintenance effort, and environmental impact.

Renewable energy sources such as solar and wind are often intermittent and dependent on environmental conditions. As a result, there is a growing interest in alternative energy-harvesting techniques that can operate continuously in agricultural environments. Plant Microbial Fuel Cells (PMFCs) offer a promising solution by generating electrical energy from naturally occurring biological processes in soil [3], enabling autonomous and sustainable agricultural monitoring systems.

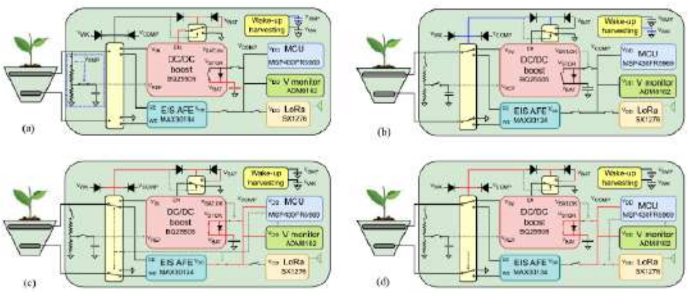

Fig. 1: Block diagram of a PMFC-based smart agriculture system [1].

Working Principle of Plant Microbial Fuel Cells

A Plant Microbial Fuel Cell is a type of microbial fuel cell that converts chemical energy into electrical energy through microbial metabolism [1]. During photosynthesis, plants produce organic compounds, a portion of which are released into the soil through root exudates. These compounds act as a nutrient source for soil microorganisms.

Microorganisms present in the anaerobic region of the soil oxidize the organic matter and release electrons as part of their metabolic processes. An anode placed in this region collects the electrons, while a cathode positioned near the soil surface facilitates the reduction reaction using oxygen. The movement of electrons through an external circuit generates electrical power.

PMFC as an Energy Source and Biosensing Platform

The electrical output of PMFCs is relatively low, typically in the range of a few hundred millivolts [3]. However, when combined with suitable energy harvesting circuits such as DC–DC converters and energy storage elements like supercapacitors, the harvested energy becomes sufficient for ultra-low-power electronic systems.

In addition to energy generation, PMFCs can function as biosensors. Electrical parameters such as voltage, current, and impedance are influenced by soil moisture, microbial activity, and plant physiological conditions. Techniques such as Electrochemical Impedance Spectroscopy (EIS) enable real-time monitoring of these variations.

Integration with Wireless IoT Systems

PMFC-based systems can be integrated with low-power wireless communication technologies such as LoRa, which is widely used in agricultural Internet of Things (IoT) applications due to its long communication range and low energy consumption [2]. Sensor nodes powered by PMFCs can operate in duty-cycled modes, where sensing and data transmission occur periodically.

This approach enables efficient utilization of harvested energy and supports large-scale deployment of sensor networks across agricultural fields.

Challenges in PMFC Technology

Despite their advantages, PMFCs face several challenges:

- **Low Power Density:** PMFCs generate limited power, restricting their application to low-energy systems.
- **Environmental Dependence:** Performance varies with soil type, plant species, and environmental conditions.
- **Slow Startup Time:** Biofilm formation on electrodes requires time, leading to delayed stable operation.

Conclusion

Plant Microbial Fuel Cells present a sustainable and innovative approach to powering smart agricultural systems. By utilizing naturally occurring biological processes, PMFCs enable continuous energy harvesting while simultaneously providing insights into soil and plant health.

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