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Millimeter Wave in Internet of Things Connectivity: A Study

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Abstract

The internet of things (IoT) is rapidly evolving, connecting billions of devices and transforming industries. However, this growth is stretching the limitations of traditional wireless communication technologies. Enter millimeter wave (mmWave), a high-frequency band promising to revolutionize IoT connectivity by offering significantly higher bandwidth and lower latency. While still in its early stages of implementation, mmWave is poised to become a cornerstone of the next generation of IoT ecosystems. Millimeter waves operate within the 30 GHz to 300 GHz frequency range, offering a significantly larger spectrum compared to the lower frequencies commonly used in Wi-Fi and cellular networks. This extensive bandwidth enables ultra-fast data transfer speeds, making mmWave technology ideal for applications that require high throughput and real-time communication. With the rapid growth of the IoT, the demand for greater bandwidth continues to rise as more connected devices generate massive amounts of data. While sub-6 GHz frequencies have been effective, the need for faster speeds and reduced latency has shifted focus toward mmWave technology. Operating in the 30 GHz to 300 GHz range, mmWave offers vast spectrum resources and the potential for multi-gigabit speeds. However, implementing mmWave in IoT presents unique design challenges. This article explores the key steps involved in navigating these challenges and harnessing the power of mmWave for enhanced IoT communication.

Keywords: Millimeter wave (mmWave), internet of things (IoT), bandwidth, spectrum, high frequency

INTRODUCTION

Millimeter wave (mmWave) technology operates within the 30 to 300 gigahertz (GHz) range of the radio frequency spectrum. Unlike conventional Wi-Fi and cellular networks that use lower frequencies, mmWave functions at much higher frequencies, offering significantly greater bandwidth. This translates to a substantial boost in data transfer capacity, much like upgrading from a narrow two-lane road to a wide, multi-lane expressway [1–10]. The benefits of mmWave for internet of things (IoT) are substantial:

High Bandwidth

The biggest benefit is the significantly higher bandwidth, enabling fast data transfer. This is essential for tasks such as streaming high-definition videos, analyzing real-time data, and managing advanced sensor networks that handle vast amounts of information.

Low Latency

The high frequencies of mmWave help reduce latency, ensuring that data is transmitted almost instantly with minimal delay. This is critical for time-sensitive applications like autonomous vehicles, industrial automation, and remote surgery, where even a fraction of a second can make a difference.

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Increased Capacity

Millimeter wave technology enables a significantly higher number of connected devices than conventional wireless networks. This makes it perfect for crowded areas such as smart cities, factories, and stadiums, where multiple devices must communicate at the same time without causing network congestion.

Reduced Interference

Millimeter wave frequencies experience less interference from other wireless signals, ensuring more stable and reliable data transmission.

Enhanced Security

The concentrated nature of mmWave signals can improve security by making it more difficult to intercept data transmissions.

The impact of mmWave on the IoT spans a wide range of applications, including:

- *Smart Cities:* mmWave technology enables the high-density sensor networks needed for smart street lighting, traffic control, environmental monitoring, and public safety applications [11–15].
- *Industrial IoT (IIoT):* mmWave facilitates real-time monitoring and control of industrial equipment, enabling predictive maintenance, automation, and improved efficiency in manufacturing processes.
- *Connected Vehicles:* mmWave is crucial for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, providing the high bandwidth and low latency necessary for autonomous driving and advanced driver-assistance systems (ADAS).
- *Healthcare:* mmWave can enable remote patient monitoring, wearable medical devices, and high-resolution medical imaging, revolutionizing healthcare delivery.
- *Augmented Reality and Virtual Reality (AR/VR):* High-bandwidth connectivity is essential for a seamless AR/VR experience. mmWave can deliver the necessary speed and low latency for immersive applications.
- *Smart Retail:* mmWave can power interactive and personalized shopping experiences through smart shelves, real-time inventory management, and customer tracking [16–20].

Despite its potential, mmWave technology also faces some challenges:

- *Limited Range:* mmWave signals are susceptible to atmospheric absorption and have a shorter range compared to lower frequencies. This requires a denser network infrastructure with multiple access points.
- *Obstruction Issues:* mmWave signals are easily blocked by obstacles like buildings and trees. This necessitates careful planning and strategic placement of antennas.
- *Cost:* Deploying mmWave infrastructure can be more expensive than traditional technologies due to the need for specialized hardware and a denser network.
- *Power Consumption:* Developing energy-efficient devices that can operate at high mmWave frequencies is a continuous area of research [21–25].

Despite the challenges, the future of mmWave in IoT looks bright. Continuous research and innovation are helping to overcome these obstacles, making mmWave solutions more affordable and efficient. With the expansion of 5G networks and the rising need for high-speed data, various technologies are coming together to enhance connectivity. As mmWave technology advances, it will become a key driver in unlocking the full potential of IoT, paving the way for a smarter, more connected, and efficient world.

Millimeter wave technology is not just a next-generation upgrade; it is a paradigm shift in wireless communication. With its vast bandwidth, minimal delay, and enhanced capacity, mmWave is set to transform the IoT, creating a more intelligent and connected world. As advancements continue and challenges are addressed, this technology will seamlessly integrate into our daily lives, driving the future of smart devices and digital experiences [26–30].

MILLIMETER WAVE IN INTERNET OF THINGS COMMUNICATION

IoT is growing at a remarkable pace, linking billions of devices across homes, industries, and urban areas. This expanding network requires strong and dependable communication solutions to ensure seamless connectivity. While technologies like Wi-Fi and Bluetooth have served well, the growing volume of data and the need for higher bandwidth are pushing the limits of these traditional options. Enter mmWave technology, a promising contender poised to revolutionize IoT connectivity.

Unlike the lower frequencies used by Wi-Fi and cellular networks, mmWave operates at significantly higher frequencies, giving it unique properties. This includes:

- *Higher Bandwidth:* mmWave offers vast amounts of spectrum, allowing for extremely fast data rates. This is crucial for IoT applications requiring high-definition video streaming, real-time sensor data transmission, and other bandwidth-intensive tasks.
- *Lower Latency:* The higher frequencies and wider channels of mmWave translate to lower latency, which is essential for applications needing rapid response times, such as autonomous vehicles and industrial automation.
- *Shorter Range:* Because of increased atmospheric absorption, mmWave signals have a more limited range than lower frequency signals. This limitation, however, can be advantageous for creating dense, localized networks, reducing interference and improving security in crowded environments.

The potential of mmWave for IoT is substantial:

- *Industrial IoT (IIoT):* In factories and industrial settings, mmWave can enable wireless control of machinery with low latency and high bandwidth, facilitating real-time monitoring, predictive maintenance, and fully automated processes. This can enhance efficiency, reduce downtime, and improve worker safety.
- *Smart Cities:* mmWave can power smart city initiatives, supporting applications such as intelligent traffic management, high-speed public Wi-Fi, and advanced public safety systems. The high capacity allows for the handling of massive data streams from numerous sensors and devices [31–35].
- *Healthcare:* Remote patient monitoring, telemedicine, and advanced medical imaging all benefit from the high data rates and low latency offered by mmWave. It can enable faster and more accurate diagnoses and treatment, revolutionizing healthcare delivery.
- *Smart Homes and Buildings:* mmWave can support high-speed connectivity for smart devices within a home, enabling seamless streaming of high-definition content, reliable smart home automation, and augmented reality experiences. It can also enhance building automation with smart sensors and control systems.
- *Agriculture:* Precision agriculture applications such as drone-based monitoring, soil analysis, and automated irrigation systems can greatly benefit from mmWave's ability to transmit large amounts of data from multiple sources with low latency.

Despite these challenges, the opportunities are immense:

- *Advanced Beamforming and Tracking:* Development of sophisticated beamforming and beam tracking techniques are allowing for more reliable mmWave communication in complex environments.
- *Integration with Existing Infrastructure:* Integrating mmWave with existing low-frequency networks will create hybrid networks that are more efficient and resilient.
- *Chipset Advancements:* The cost of mmWave hardware will likely decrease as the technology matures and chipsets become more affordable [36–40].

Millimeter wave is poised to play a pivotal role in the evolution of IoT. Its high bandwidth, low latency, and ability to support a high density of devices make it exceptionally well-suited for the increasingly complex demands of modern IoT applications. As technological advancements continue, mmWave is expected to become an integral part of our interconnected world, enabling transformative applications that will reshape industries and enhance our daily lives. While challenges remain, the industry is eagerly exploring and investing in mmWave, recognizing its potential to unlock a new era of IoT communication.

In essence, mmWave technology presents a strong alternative to current IoT communication options. With its ability to deliver high bandwidth and low latency, it holds the potential to transform multiple industries. Although there are challenges to address, ongoing research and development in this area offer promising prospects for the future of mmWave in IoT.

IMPACT OF MILLIMETER WAVE ON INTERNET OF THINGS APPLICATIONS

IoT is quickly revolutionizing our world by linking everything from smart home gadgets to industrial sensors and self-driving cars. However, the massive amount of data produced by these interconnected devices is putting growing pressure on current wireless communication networks. This is where mmWave technology steps into the spotlight, poised to unlock the next level of IoT capabilities [41–45].

The advantages of mmWave are having a significant impact on various IoT applications:

- *Smart Cities:* mmWave is crucial for supporting the data-heavy applications within smart cities, including:
  - *Advanced Traffic Management:* Real-time traffic monitoring, adaptive traffic light control, and autonomous vehicle communication.
  - *Environmental Monitoring:* High-resolution data collection from environmental sensors, enabling precise pollution tracking and effective resource management.
  - *Public Safety:* Enhanced video surveillance and emergency response systems.
- *Industrial IoT (IIoT):* mmWave is transforming industrial processes by enabling:
  - *Real-Time Machine Monitoring:* High-fidelity sensor data from factory equipment, enabling predictive maintenance and reducing downtime.
  - *Robotics and Automation:* Rapid and reliable communication for controlling robots and automated systems on factory floors.
  - *Wireless Industrial Networks:* High-speed connectivity for seamless integration of various industrial devices.
- *Smart Healthcare:* mmWave enables the following in the healthcare industry:
  - *Remote Patient Monitoring:* High-bandwidth data transmission of medical vitals and imaging for remote patient care.
  - *Advanced Medical Imaging:* Faster and more detailed scans for improved diagnostics.
  - *Robotic Surgery:* Low-latency communication for precise control during complex surgical procedures.
- *Smart Homes and Buildings:* mmWave is improving the user experience in smart environments:
  - *Seamless Streaming:* High-speed wireless streaming of 4K/8K video and other high-bandwidth content.
  - *Enhanced Device Control:* Low-latency control of smart appliances and home automation systems.
  - *Advanced Security Systems:* Faster and more reliable video transmission for security cameras.

Millimeter wave technology is not just a promising upgrade to existing wireless communication; it is a fundamental shift that is poised to revolutionize the IoT. By providing unprecedented bandwidth, low latency, and reduced congestion, mmWave is set to power the next generation of IoT applications, enabling smarter cities, industries, healthcare systems, and homes. While implementation challenges remain, the potential benefits of mmWave are so significant that its widespread adoption is almost inevitable, shaping our future towards a more interconnected and data-driven world [46–50].

BEYOND WI-FI: MILLIMETER WAVE BRINGS HIGH-SPEED CONNECTIVITY TO INTERNET OF THINGS

IoT is rapidly expanding, linking everything from smart thermostats to industrial sensors. As the number of connected devices increases, the need for faster and more dependable communication also rises. While Wi-Fi and Bluetooth are staples, they often struggle with bandwidth limitations and congestion, especially in dense environments. Enter mmWave technology – a once-exclusive realm of mobile networks, now poised to revolutionize IoT connectivity for everyone.

What is mmWave wave and why is it relevant to IoT?

Unlike traditional wireless technologies that operate on lower frequencies, mmWave utilizes the much higher frequency bands between 30 GHz and 300 GHz. This has several key advantages:

- *Massive Bandwidth:* The higher frequencies allow for vastly greater bandwidth, enabling significantly faster data transfer rates – think gigabits per second. This is crucial for IoT devices that need to stream high-resolution video, process complex data in real-time, or handle large volumes of sensor information.
- *Reduced Congestion:* The higher frequency bands are less congested than the crowded lower frequencies used by Wi-Fi, Bluetooth, and even cellular networks. This means less interference and a more stable connection.
- *Low Latency:* mmWave provides extremely low latency, making it perfect for real-time applications such as autonomous vehicles, robotics, and augmented reality.

While mmWave was initially limited to expensive and complex infrastructure, advancements in chip technology and the increasing demand for high-speed connectivity are making it more accessible to a broader range of users, including IoT developers and hobbyists:

- *Affordable Hardware:* The cost of mmWave components, such as transceivers and antenna arrays, is steadily dropping. We are starting to see smaller, more integrated mmWave modules becoming available, paving the way for incorporation into smaller and lower-cost IoT devices [51–57].
- *Simplified Integration:* Manufacturers are developing easier-to-use modules with pre-designed circuits and software libraries, reducing the complexity of integrating mmWave into existing IoT platforms. This makes it much more approachable for developers who may not have extensive RF engineering experience.
- *Open Standards and Support:* The industry is working on standardized mmWave protocols and providing better documentation and support through online resources and communities. This helps to lower the barrier to entry and empowers individuals to experiment and develop innovative applications.
- *Emerging Ecosystem:* A growing ecosystem of companies is developing mmWave-based solutions specifically tailored to IoT applications. This means a broader range of off-the-shelf components and development kits are becoming available, making it easier to implement mmWave technology into various projects.

While not yet as ubiquitous as Wi-Fi, mmWave's potential is undeniable. Here are some potential applications where individuals can explore its uses:

- *High-Resolution Video Streaming:* Imagine live video surveillance systems or drone feeds streaming in 4K resolution without any buffering. mmWave can make this a reality.
- *Real-Time Data Analytics:* mmWave could enable faster and more frequent data transfer from sensors in industrial environments, allowing for real-time monitoring and predictive maintenance.
- *Robotics and Automation:* Explore controlling robots and automated systems with greater precision and feedback, thanks to the low latency and high bandwidth of mmWave.

- *Smart Home Networking:* mmWave could be used to create a high-capacity local network in your home, handling multiple high-bandwidth devices without bottlenecks.
- *Advanced Wearables:* Future generations of wearables could benefit from mmWave for features like high-fidelity audio streaming, detailed sensor data analysis, and augmented reality experiences.

While mastering mmWave technology takes time and effort, the following tips can help you get started:

- *Research Existing Platforms:* Explore development kits and modules that offer mmWave support. Manufacturers like Texas Instruments, Qualcomm, and Silicon Labs often provide resources for developers.
- *Study the Basics of Antenna Design:* Understanding how antennas operate is crucial for optimizing mmWave communication. While pre-designed antennas exist, knowing the fundamentals can enhance your project design.
- *Experiment with Software Tools:* Explore software libraries and development tools that simplify the integration of mmWave into your applications.
- *Join Online Communities:* Connect with other developers and experts in mmWave technology to share knowledge and learn from each other.
- *Start Small:* Begin with a simple proof-of-concept project to get comfortable with the technology before tackling more complex applications.

mmWave technology is rapidly evolving and becoming more accessible. While challenges still exist, the promise of high-speed, low-latency communication is making it increasingly attractive for the future of IoT. By embracing and exploring this technology, individuals can pave the way for more innovative and powerful IoT applications that will shape the future of connectivity. The path to ubiquitous mmWave IoT is steadily being forged, and you have a chance to be a part of it.

NAVIGATING THE DESIGN STEPS FOR HIGH-BANDWIDTH INTERNET OF THINGS CONNECTIVITY

As IoT is rapidly expanding, demanding ever-increasing bandwidth to support the multitude of connected devices and their data-intensive applications. While traditional sub-6 GHz frequencies have served well, the quest for faster data rates and lower latency has turned attention towards mmWave technology. Operating in the 30 GHz to 300 GHz range, mmWave offers vast spectrum resources and the potential for multi-gigabit speeds. However, implementing mmWave in IoT presents unique design challenges. This article explores the key steps involved in navigating these challenges and harnessing the power of mmWave for enhanced IoT communication.

Application and Use Case Analysis: Defining the Needs

Before diving into technical specifications, the crucial first step is a thorough analysis of the intended application and use case. This involves asking critical questions such as:

- *Data Rate Requirements:* How much bandwidth is needed? Will it be consistent or bursty? Consider current needs and future scalability.
- *Range and Coverage:* How far apart will devices be? Does the system need to cover a small area like a room or a larger area like a factory floor?
- *Mobility:* Will devices be stationary or mobile? mmWave signals are susceptible to blockage and require careful planning for moving devices.
- *Environmental Conditions:* How will factors like weather, humidity, and obstacles impact signal propagation?
- *Power Consumption:* mmWave transceivers are generally more power-hungry. Power requirements must be optimized for battery-powered IoT devices.
- *Cost Constraints:* mmWave components can be more expensive. Analyze cost trade-offs considering performance requirements.

A clear understanding of these requirements will dictate the subsequent design choices.

Spectrum Selection and Regulatory Compliance

Choosing the appropriate mmWave frequency band is critical. Different regions have distinct spectrum allocations for license-exempt and licensed operation. Considerations include:

- *Available Spectrum Allocation:* Identifying the specific frequency bands available within the target region.
- *Licensing Requirements:* Understanding the licensing process for assigned bands, if required.
- *Interference Mitigation:* Considering potential interference from other mmWave systems and implementing techniques to mitigate it.
- *Global Compliance:* Understanding different regulations across countries if targeting a multinational market.

Meticulous adherence to regulatory requirements is essential for legal and efficient operation.

Antenna Design: Mastering Beamforming and Directionality

Millimeter wave signals suffer from high propagation loss and susceptibility to blockage. This necessitates the use of directive antennas with beamforming capabilities to compensate for these challenges:

- *Antenna Array Design:* Implementing phased array antennas to create directional beams that can be steered electronically. This is critical for adapting to changes in the environment and device movement.
- *Gain and Beamwidth:* Optimizing antenna gain to achieve the required range and minimizing beamwidth for focused signal transmission.
- *Polarization:* Choosing appropriate polarization for efficient signal propagation and minimizing signal loss.
- *Integration:* Integrating the antennas into the IoT device while considering size, weight, and cost constraints.

Advanced antenna design is paramount to achieving reliable mmWave communication.

Transceiver Design: Balancing Performance and Power

The mmWave transceiver is the heart of the system, responsible for signal generation, reception, and processing. Key considerations include:

- *Radio Frequency (RF) Front-End:* Designing low-noise amplifiers (LNAs), mixers, and other RF components suitable for the high frequencies.
- *Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs):* Ensuring high-performance ADCs and DACs are used to accurately process the wideband mmWave signals.
- Modulation and Coding: Selection of modulation schemes (e.g., orthogonal frequency division multiplexing [OFDM]) and coding techniques to optimize data rate and robustness.
- *Power Management:* Optimizing power consumption of the transceiver to extend battery life in IoT devices.
- *Integration:* Integrating the transceiver components into a compact and cost-effective unit.

Efficient transceiver design is crucial for achieving the desired performance and energy efficiency.

Signal Processing and Protocol Implementation

Processing the mmWave signals and implementing communication protocols is essential for reliable data transfer:

- *Digital Beamforming:* Performing digital signal processing to control beam direction and achieve optimal signal reception.

- *Channel Estimation and Equalization:* Compensating for channel impairments and ensuring reliable data transmission.
- *Medium Access Control (MAC) Protocols:* Selecting appropriate protocols for managing access to the shared channel among multiple devices.
- *Security:* Implementing security mechanisms such as encryption to protect data and prevent unauthorized access.
- *Software Defined Radio (SDR) Capabilities:* Considering the use of SDRs to provide flexibility in implementing and upgrading protocols.

Robust signal processing and protocol design ensure reliable and secure communication.

System Integration and Testing

Finally, the separate components must be integrated into a cohesive system and thoroughly tested:

- *Hardware Integration:* Integrating the mmWave components with other IoT hardware.
- *Software Integration:* Integrating the software for signal processing, protocol management, and application logic.
- *Performance Testing:* Thoroughly testing the system in various scenarios and environmental conditions to ensure it meets the requirements.
- *Interoperability Testing:* Testing the interoperability with other standards and devices.

Rigorous testing is essential to ensure the reliability and proper functioning of the integrated system.

CONCLUSION

Implementing mmWave technology in IoT communication offers transformative potential for high-bandwidth applications. However, careful consideration of all design steps is essential for success. By systematically addressing the challenges, optimizing each stage from application analysis to system testing, and prioritizing both cost and performance, developers can unlock the full potential of mmWave for creating innovative and powerful IoT solutions. As mmWave technology matures and becomes more cost-effective, its integration into the IoT landscape will undoubtedly pave the way for smarter, more connected, and data-rich environments. Implementing mmWave technology in IoT communication offers transformative potential for high-bandwidth applications. However, careful consideration of all design steps is essential for success. By systematically addressing the challenges, optimizing each stage from application analysis to system testing, and prioritizing both cost and performance, developers can unlock the full potential of mmWave for creating innovative and powerful IoT solutions. As mmWave technology matures and becomes more cost-effective, its integration into the IoT landscape will undoubtedly pave the way for smarter, more connected, and data-rich environments.

REFERENCES

1. Liyakat KKS. Microwave communication in the internet of things: a study. J RF Microw Commun Technol. 2024; 1 (3): 38–49.
2. Liyakat KKS. Machine learning approach using artificial neural networks to detect malicious nodes in IoT networks. In: Shukla PK, Mittal H, Engelbrecht A, eds. International Conference on Machine Learning, IoT and Big Data 2023. Singapore: Springer Nature; 2023. pp. 123–134.
3. Pradeepa M, Jamberi K, Sajith S, Bai MR, Prakash A. Student health detection using a machine learning approach and IoT. In: 2022 IEEE 2nd Mysore Sub Section International Conference (MysuruCon), Mysuru, India, October 16–17, 2022. pp. 1–5.
4. Liyakat KKS. Detecting malicious nodes in IoT networks using machine learning and artificial neural networks. In: 2023 International Conference on Emerging Smart Computing and Informatics (ESCI), Pune, India, March 1–3, 2023. pp. 1–5.
5. Kasat K, Shaikh N, Rayabharapu VK, Nayak M, Liyakat KKS. Implementation and recognition of waste management system with mobility solution in smart cities using internet of things. In: 2023 Second International Conference on Augmented Intelligence and Sustainable Systems (ICAISS), Trichy, India, August 23–25, 2023. pp. 1661–1665.

6. Ghorbanzadeh O, Blaschke T, Gholamnia K, Meena SR, Tiede D, Aryal J. Evaluation of different machine learning methods and deep-learning convolutional neural networks for landslide detection. Remote Sens. 2019;11(2):196. DOI: 10.3390/rs11020196.
7. Kazi K. AI-driven IoT (AIIoT) in healthcare monitoring. In: Nguyen TVT, Vo NTM, editors. Using Traditional Design Methods to Enhance AI-Driven Decision Making. Hershey, PA, USA: IGI Global; 2024. pp. 77–101.
8. Khadake S, Kawade S, Moholkar S, Pawar M. A review of 6G technologies and its advantages over 5G technology. In: Pawar PM, Ronge BP, Gidde RR, editors. Techno-Societal 2022 International Conference on Advanced Technologies for Societal Applications 2022. Cham, Switzerland: Springer International Publishing; 222. pp. 1043–1051.
9. Patil VJ, Khadake SB, Tamboli DA, Mallad HM, Takpere SM, Sawant VA. Review of AI in power electronics and drive systems. In: 2024 3rd International Conference on Power Electronics and IoT Applications in Renewable Energy and Its Control (PARC), Mathura, India, February 23–24, 2024. pp. 94–99.
10. Kazi K. Modelling and simulation of electric vehicle for performance analysis: BEV and HEV electrical vehicle implementation using Simulink for e-mobility ecosystems. In: Lakshmi D, Nagpal N, Kassarwani N, Vishnu Varthanan G, Siano P, editors. E-Mobility in Electrical Energy Systems for Sustainability. Hershey, PA, USA: IGI Global; 2024. pp. 295–320.
11. Kazi KS. Computer-aided diagnosis in ophthalmology: a technical review of deep learning applications. In: Garcia MB, de Almeida RPP, editors. Transformative Approaches to Patient Literacy and Healthcare Innovation. Hershey, PA, USA: IGI Global; 2024. pp. 112–135.
12. Liyakat KKS, Magadum PK. Machine learning for predicting wind turbine output power in wind energy conversion systems. Grenze Int J Eng Technol. 2024; 10: 2074–2080.
13. Nerkar PM, Liyakat KK, Dhaware BU, Liyakat KS. Predictive data analytics framework based on heart healthcare system (HHS) using machine learning. J Adv Zool. 2023; 44: 3673–3686.
14. Neeraja P, Kumar RG, Kumar MS, Liyakat KK, Vani MS. DL-based somnolence detection for improved driver safety and alertness monitoring. In: 2024 IEEE International Conference on Computing, Power and Communication Technologies (IC2PCT), Greater Noida, India, February 9–10, 2024. Vol. 5, pp. 589–594.
15. Liyakat KK. Explainable AI in healthcare. In Kamaraj AA, Acharjya DP, editors. Explainable Artificial Intelligence in Healthcare Systems. Hauppauge, NY, USA: Nova Publishers; 2024. pp. 271–284.
16. Kazi KS. ChatGPT: an automated teacher's guide to learning. In: Bansal R, Chakir A, Ngah AH, Rabby F, Jain A, editors. AI Algorithms and ChatGPT for Student Engagement in Online Learning. Hershey, PA, USA: IGI Global; 2024. pp. 1–20.
17. Veena C, Sridevi M, Liyakat KK, Saha B, Reddy SR, Shirisha N. HEECCNB: an efficient IoT-cloud architecture for secure patient data transmission and accurate disease prediction in healthcare systems. In: 2023 Seventh International Conference on Image Information Processing (ICIIP), Solan, India, November 22–24, 2023. pp. 407–410.
18. Prasad KR, Karanam SR, Ganesh D, Liyakat KK, Talasila V, Purushotham P. AI in public-private partnership for IT infrastructure development. J High Technol Manage Res. 2024; 35 (1): 100496.
19. Kazi KS. IoT driven by machine learning (MLIoT) for the retail apparel sector. In: Tarnanidis TK, Papachristou E, Karypidis M, Ismyrlis M, editors. Driving Green Marketing in Fashion and Retail. Hershey, PA, USA: IGI Global; 2024. pp. 63–81.
20. Dudgikar AB, Ingalgi AA, Jamadar AG, Swami OR, Khadake SB, Moholkar SV. Intelligent battery swapping system for electric vehicles with charging stations locator on IoT and cloud platform. Int J Adv Res Sci Commun Technol. 2023; 3 (1): 204–208.
21. Khadake SB, Patil VJ. Prototype design & development of solar based electric vehicle. In: 2023 3rd International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON), Bangalore, India, December 29–31, 2023. pp. 1–7.
22. Patil VJ, Khadake SB, Tamboli DA, Mallad HM, Takpere SM, Sawant VA. A comprehensive analysis of artificial intelligence integration in electrical engineering. In: 2024 5th International Conference on Mobile Computing and Sustainable Informatics (ICMCSI), Lalitpur, Nepal, January 18–19, 2024. pp. 484–491.

23. Kazi KS. Machine learning (ML)-based Braille Lippi characters and numbers detection and announcement system for blind children in learning. In: Sart G, editor. Social Reflections of Human-Computer Interaction in Education, Management, and Economics. Hershey, PA, USA: IGI Global; 2024. pp. 16–39.
24. Kazi KS. Artificial intelligence (AI)-driven IoT (AIIoT)-based agriculture automation. In: Satapathy S, Muduli K, editors. Advanced Computational Methods for Agri-Business Sustainability. Hershey, PA, USA: IGI Global; 2024. pp. 72–94.
25. Khadake SB, Dolli SP, Rathod KS, Waghmare MO, Deshpande MA. An overview of intelligent traffic control system using PLC and use of current data of vehicle travels. JournalNX – A Multidiscipl Peer Reviewed J. 2016; Feb 12: VESCOMM 12.
26. Sayyad Liyakat KK, Konnur RG. Vehicle health monitoring system (VHMS) by employing IoT and sensors. Grenze Int J Eng Technol. 2024; 10: 5367–5374.
27. Magar SS, Sugandhi AS, Pawar SH, Khadake SB, Mallad HM. Harnessing wind vibration, a novel approach towards electric energy generation – review. Int J Adv Res Sci Commun Technol. 2024; 4 (2): 73–82.
28. Khadake SB, Padavale PV, Dhere PM, Lingade BM. Automatic hand dispenser and temperature scanner for Covid-19 prevention. Int J Adv Res Sci Commun Technol. 2023; 3 (2): 362–367. doi: 10.48175/IJARSCT-11364.
29. Biradar PK, Pardeshi YS, Bagwan IA, Kazi TI, Ganji SS. Remotely operated video enhanced receiver. Int J Creative Res Thoughts. 2024; 12 (3): h446–h454.
30. Landage SS, Chavan SR, Kokate PA, Lohar SP, Pawar MK, Khadake SB. Solar outdoor air purifier with air quality monitoring system. Synergies of Innovation: Proceedings of NCSTEM, Pandharpur, India, September 2024. pp. 260–266.
31. Khadake SB. Detecting salient objects of natural scene in a video's using spatio-temporal saliency & colour map. JournalNX – A Multidiscipl Peer Reviewed J. 2016; 2 (8): 30–35.
32. Liyakat KK, Kutubuddin K. IoT based boiler health monitoring for sugar industries. In: 15th International Conference on Advances in Computing, Control, and Telecommunication Technologies, ACT 2024, Hyderabad, India, June 21–22, 2024. Vol. 2, pp. 5178–5185.
33. Kazi KS. Machine learning-based pomegranate disease detection and treatment. In: Zia Ul Haq M, Ali I, editors. Revolutionizing Pest Management for Sustainable Agriculture. Hershey, PA, USA: IGI Global; 2024. pp. 469–498.
34. Aquino AI, Calautit JK, Hughes BR. Integration of aero-elastic belt into the built environment for low-energy wind harnessing: Current status and a case study. Energy Convers Manag. 2017;149:830-50. DOI: 10.1016/j.enconman.2017.03.030.
35. Khadake SB, Khedekar SV, Kawade AM, Vyavahare SS, Kashid PJ, Chounde Amol B, Mallad HM. Solar based electric vehicle charging system. Int J Adv Res Sci Commun Technol. 2024; 4 (2): 42–57.
36. Kazi KS. IoT technologies for the intelligent dairy industry: A new challenge. In: Thandekkattu SG, Vajjhala NR, editors. Designing Sustainable Internet of Things Solutions for Smart Industries. Hershey, PA, USA: IGI Global; 2025. pp. 321–350.
37. Khan S, Ahmad A, Ahmad F, Shafaati Shemami M, Saad Alam M, Khateeb S. A comprehensive review on solar powered electric vehicle charging system. Smart Sci. 2018;6(1):54-79. DOI: 10.1080/23080477.2017.1419054.
38. Khadake SB, Kashid PJ, Kawade AM, Khedekar SV, Mallad HM. Electric vehicle technology battery management – review. Int J Adv Res Sci Commun Technol. 2023; 3 (2): 319–325.
39. Liyakat KK. Heart health monitoring using IoT and machine learning methods. In: Shaik A, editor. AI-Powered Advances in Pharmacology. Hershey, PA, USA: IGI Global; 2025. pp. 257–282.
40. Chounde A, Gopnarayan BB, Patil KB, Kamble SS. Human health care system: a new approach towards life. Grenze Int J Eng Technol. 2024; 10 (2): 5487–5494.
41. Khadake SB, Patil VJ, Mallad HM, Gopnarayan BB, Patil KB. Maximize farming productivity through agriculture 4.0 based intelligence, with use of agri tech sense advanced crop monitoring system. Grenze Int J Eng Technol. 2024; 10 (2): 5127–5134.

42. Kazi KS. AI-driven-IoT (AIIoT)-based decision making in kidney diseases patient healthcare monitoring: KSK approach for kidney monitoring. In: Polat LÖ, Polat O, editors. AI-Driven Innovation in Healthcare Data Analytics. Hershey, PA, USA: IGI Global; 2025. pp. 277–306.
43. Kazi KS. AI-driven-IoT (AIIoT)-based decision making in drones for climate change: KSK approach. In Aouadni S, Aouadni I, editors. Recent Theories and Applications for Multi-Criteria Decision-Making. Hershey, PA, USA: IGi Global; 2025. pp. 311–340. doi: 10.4018/979-8-3693-6502-1.ch011.
44. Yuan Q, Zhang H, Deng T, Tang S, Yuan X, Tang W, et al. Role of artificial intelligence in kidney disease. Int J Med Sci. 2020;17(7):970-84. DOI: 10.7150/ijms.42078, PubMed: 32308551.
45. Mahant MA. Machine learning-driven internet of things (MLIoT)-based healthcare monitoring system. In Wickramasinghe N, editor. Digitalization and the Transformation of the Healthcare Sector. Hershey, PA, USA: IGi Global; 2025. pp. 205–236. doi: 10.4018/979-8-3693-9641-4.ch007.
46. Nerkar P, Kazi S. IoT-based skin health monitoring system. Int J Biol Pharm All Sci. 2024; 13 (11): 5937–5950. doi: 10.31032/IJBPAS/2024/13.11.8488.
47. Kazi KSL. AI-powered IoT (AI IoT) for decision-making in smart agriculture: KSK approach for smart agriculture. In Hai-Jew S, editor. Enhancing Automated Decision-Making Through AI. Hershey, PA, USA: IGI Global; 2025. pp. 67–96. doi: 10.4018/979-8-3693-6230-3.ch003.
48. Kazi KSL. KK approach to increase resilience in internet of things: a T-cell security concept. In: Darwish D, Charan K, editors. Analyzing Privacy and Security Difficulties in Social Media: New Challenges and Solutions. Hershey, PA, USA: IGIG Global; 2025. pp. 87–120. doi: 10.4018/979-8-3693-9491-5.ch005.
49. Kazi KS. Machine learning-driven internet of medical things (ML-IoMT)-based healthcare monitoring system. In Soufiene B, Chakraborty C, editors. Responsible AI for Digital Health and Medical Analytics. Hershey, PA, USA: IGI Global; 2025. pp. 49–86. doi: 10.4018/979-8-3693-6294-5.ch003.
50. Ullo SL, Sinha GR. Advances in IoT and smart sensors for remote sensing and agriculture applications. Remote Sens. 2021;13(13):2585. DOI: 10.3390/rs13132585.
51. Chandra Mouli GR, Bauer P, Zeman M. System design for a solar powered electric vehicle charging station for workplaces. Appl Energy. 2016;168:434-43. DOI: 10.1016/j.apenergy.2016.01.110.
52. Randive AB, Gaikwad SK, Khadake SB, Mallad HM. Biodiesel: a renewable source of fuel. Int J Adv Res Sci Commun Technol. 4 (3): 225–240. doi: 10.48175/IJARSCT-22836.
53. Kazi K. A novel approach on ML based palmistry. Grenze Int J Eng Technol. 2024; 10 (2): 5186–5193.
54. Kazi K. IoT based boiler health monitoring for sugar industries. Grenze Int J Eng Technol. 2024; 10 (2): 5178–5185.
55. Bilal B, Ndongo M, Adjallah KH, Sava A, Kébé CMF, Ndiaye PA, et al. Wind turbine power output prediction model design based on artificial neural networks and climatic spatiotemporal data. 2018 IEEE International Conference on Industrial Technology (ICIT), Lyon, France. 2018. pp.1085-92. DOI: 10.1109/ICIT.2018.8352329.
56. Mulani AP, Bang AV, Birajadar GB, Deshmukh AB, Jadhav HM. IoT based air, water, and soil monitoring system for pomegranate farming. Ann Agri-Bio Res. 2024; 29 (2): 71–86.
57. Kazi KS. Transformation of agriculture effectuated by artificial intelligence-driven internet of things (AIIoT). In: Garwi J, Dzingirai M, Masengu R, editors. Integrating Agriculture, Green Marketing Strategies, and Artificial Intelligence. Hershey, PA, USA: IGI Global; 2025. pp. 449–484. doi: 10.4018/979-8-3693-6468-0.ch015.

