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Antennas for Autonomous Systems: Enabling Precision and Efficiency

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Abstract

A completely autonomous system will be available for numerous applications by 2030 thanks to 6G wireless networks; fully autonomous systems are one of them. Autonomous cars equipped with RADAR technology will need antennas with varying radiation zones, half-power beamwidths (HPBW), and gains to accomplish tasks like lane changing, brake emergencies, and assisted parking. This creative method is quickly becoming a game-changing innovation in wireless communication technologies. Therefore, to offer good coverage for the sixth-generation millimetre-wave frequency ranges (6G), this paper suggests a Multi Antenna Array System for Autonomous Systems (**MAAS-AS**). This system is efficient and widely used in various applications, including telemetry for autonomous vehicles and other wireless ones. A fluidic, conductive, or insulating component that can be controlled by software to dynamically change the shape and location of an antenna to vary important factors, including operating frequency, gain, radiation pattern, and other important features, is called an MAAS. Future 6G wireless networks will be heavily affected by MAAS due to their unique characteristics. The effectiveness of this antenna has been established by simulating its operation at 150 GHz resonance using the reflection coefficient (S-parameter), actual gain, and electromagnetic radiation waveforms. The Terahertz (THz) wavelength spectrum, which extends from 0.1 to 10 THz, will be used by the 6G wireless transmission network for numerous prospective purposes to fulfil consumer needs for growing bandwidth and ultra-high speed.

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Introduction

Many people in the scientific community are interested in smart antennas and adaptable arrays. When used at the base station of current wireless infrastructures, its efficient reusing of frequencies strategy delivers an excellent capacity enhancement to the radio communications system, which is resource-restricted in frequency.[1] The direction-finding capabilities of smart antennas also bring new features like automated transit, recognition of fraud, and position-location solutions for emergencies.[2, 23] A set of guiding principles defines the goals and features of the 6G. It offers throughputs of many terabytes per second, far faster than 5G, hence significantly better data transfer rates.[3] This communication technique reduces the duration of response and latency to milliseconds or even microseconds.[4, 24] Applying AI and ML throughout the system, 6G will greatly enhance immediate performance, including decreased latency and greater data throughput .[5] Further, cutting-edge authorization, encoding, and safety techniques will be used to make data even more secure. We will also investigate ways to use the radio spectrum better to expand the network's capabilities. Due to the lack of specified standards and restrictions, researchers are investigating potential 6G frequency ranges.[6, 25] To address 6G's specifications, however, researchers are looking at many possible frequency ranges. Sixth-generation wireless networks will use terahertz frequencies, which vary from a few THz to several hundred GHz.[7]

Data speeds and capacities are both greatly enhanced by these very high frequencies. However, building antennas and transmitting terahertz waves still presents technical challenges.[8, 26] Before 5G, research focused on efficient packet transport with adequate data rates and minimum interference. While problems with handling movement and dispersion of power have long plagued mobile communications, WiFi networks have recently shifted their attention to the interplay of digital intelligent devices, software-defined Ethernet (SDN), automatic immediate time actions, and other outside influences, and B5G cellular systems.[9] These integrated networking and communication technologies have caused new bandwidth, latency, jitter, and security issues. Network virtualization, architecture architecture, portability procedures, and administration are becoming complicated by several new elements, such as software-driven networks, air connections, MANETs, navigation, and the Internet of Things (IoT).[10, 27] Due to rising demand for wireless user amenities, administering, monitoring, and sustaining multi-tier HetNet cellular networks of various sizes is becoming more difficult. The ever-increasing data needs of different applications like augmented reality (AR), virtual reality (VR), autonomous automobiles (SDLs), unmanned aircraft (UAVs), robots (R), intelligent transport (ST), and 3D multimedia would enhance the customer's experiences but overwhelm current network infrastructure.[11]

Academic scholars and radio communication standardization committees have recently been captivated by 5G/B5G technologies that use AI protocols. When it comes to handling the daily data consumption of several gigabytes (GB) by people, devices, and machines, techniques based on artificial intelligence (AI) learning are essential.[12, 28] This push is driven by the challenges of managing, administering, and safeguarding mobile communication networks' massive bandwidths and producing unprecedented "big data." To address the uncoordinated, unstructured, and ungovernable challenges of future cellular networks, Various operational layers, ranging from consumers to circuit projections, are anticipated to be part of an autonomous M-MIMO modular system.[13] ML/DL technologies at the physical and upper layers of M-MIMO increase bandwidth. Complex RF and baseband processing challenges will be involved. Traditional statistical and probabilistic approaches will fail.[14, 29]

Although the radiating elements in a traditional antenna system (TAS) are typically spaced half a wavelength apart, a MAAS device can precisely configure their positions to take advantage of the entire channel variation within a given space, even in spaces that are smaller than half a wavelength.[15] This allows for more precise antenna selection. The likelihood of power outages and consumption is greatly reduced due to this adaptability. In addition, in MIMO scenarios with multiple users, each user can be given a spatial signature that maximizes their received signal and/or suppresses multi-user interference.[16] In contrast to TAS, MAAS can re-arrange the antenna positions and steering vector to reduce the traditional trade-off between signal maximization and interference nulling. Lastly, MAAS may outperform TAS in the channel hardening effect by using fewer radiating components and intelligently re-arranging their placements. Both spectral and energy efficiency are enhanced as a result.

Main contribution:

a. To solve the neighbour security issue in conventional DM methods for PLS enhancement that rely on a single antenna array, a model with numerous arrays and the AN methodology are included in the designs.
b. The receiver side mixes the usable signals by introducing the numerous antenna arrays model. Extensive design work goes into every scheme's transmitter and genuine receiver structures.
c. Hence, the proposed Multiple Antenna Array-based Autonomous systems based on 6G give the high efficiency and precision ratio of distributed spectrum bandwidth.

The following is the paper's structure: The accompanying thorough survey is located in Section 2, the suggested MAAS-AS and rationales are in Section 3, the findings and discussions are in Section 4, and the paper's conclusion is in Section 5.

Related literature survey

Briana Bryant et al. proposed a 5G and 6G millimeter-wave triple-band stacked-patch antenna (TBSPA) for DSRC[17] for use in autonomous automobile telecommunications. To demonstrate its use, the antenna's performance underwent evaluation for 6G, DSRC, and 5G, and its S-parameter achieved yield at boresight. Emission profiles were also developed and evaluated for this purpose. Simulations show a simple design and higher antenna gain than previously demonstrated triple-band antennas.

The SAGSIN and associated technologies, such as the Shape-Adaptive Antenna and Radar-Communication Integration (SAA-RCI), were introduced by Tao Hong et al.[18] Due to its construction from flexible materials, the proposed shape-adaptive antenna can change its physical form instantaneously, allowing it to produce a customized radiation beam that may be used for different purposes. A comprehensive analysis is carried out to determine the requirements and practicality of radar connection acceptance, and modeling techniques are validated and studied in detail for unmanned aerial vehicle detection.

B5G/6G systems use new technologies like the massive multiple input multiple output (mMIMO) technology suggested by Maraj Uddin Ahmed Siddiqui et al.[19] to handle the growing number of users and novel scenarios efficiently. This endeavour aims to provide researchers and operators with the necessary data to get a deeper grasp of the operational behavior and associated methodologies of B5G/6G systems, enhancing their adaptability to meet future communication demands.

According to Zhenyu Xiao et al.,[20] Multiple Antenna Arrays (MAA) can meet the increasing demands of sixth-generation (6G) wireless communications, which include long-term reliability, extensive coverage, minimal latency, and high capacity. The role of antenna arrays in facilitating networking and communications in space, the air, and land is investigated in this paper. Scientists investigate the unique benefits, difficulties, and reactions to these new developments made possible by lowland, air, and space communications.

Y. Jay Guo et al.[21] provided an exhaustive analysis of the prevalent quasi-optical techniques used by current and projected multi-beam transmitter systems. Combined with additional quasi-optical beamformers, its buildup and functioning are described in depth. As operating frequencies rise into the high millimetre-wave (mmWave) and terahertz (THz) bands, building higher-gain, multi-beam transmitters for B5G and 6G technology will primarily centre on quasi-optical approaches. Filters and mirrors work together to provide typical multiple beams with excellent gains that are compact and affordable.

Proposed method:

Avoiding interference from unintended users is essential in many applications, which is why highly directed beams are necessary. A geometrical and electrical arrangement of radiating devices may be formed to effectively boost directivity without necessarily increasing the size of the individual elements. An antenna array is a kind of radiation device that consists of many elements. When appropriately mixed in amplitude and phase, the sum of an array's electromagnetic fields is given by the vector addition of the fields emitted by each element. Varieties of array layouts include linear, circular, rectangular, and others. How the antenna's beam forms is affected by the relative positioning of its elements, the intensity and phase of its excitations, and the relative patterns of its constituent components. It is achieved by manipulating the array's results frequency and phase components and adding phase weighting throughout the array; the array pattern may be guided into a desired direction space. In addition, multiple arrays may automatically detect and eliminate environmental interference sources, which can enhance the performance of a radar system, for instance, even when no previous knowledge of the exact position of the interference is known. Adaptive arrays are often more adaptable and dependable than traditional arrays. A signal processor is a typical component of adaptive antenna arrays; it may optimize the signal-to-noise ratio by automatically adjusting the variable antenna weights using a simple adaptive approach. The targeted signal and any interference or noise are received simultaneously at the receiver's output. An adaptive antenna adjusts its emission pattern to get the best signal-to-noise ratio. The pattern's maximum is ideally facing the target signal. Adaptive arrays must be able to automatically adapt to an unknown interference environment by directing nulls and lowering side lobe levels while keeping the signal beam characteristics. This ability improves communication quality and reliability in changing or noisy environments. Adaptive arrays can effectively mitigate interference and improve overall system performance by dynamically adjusting the antenna pattern.

By using the spatial domain, smart antennas may lessen the impact of interference enhance the system's

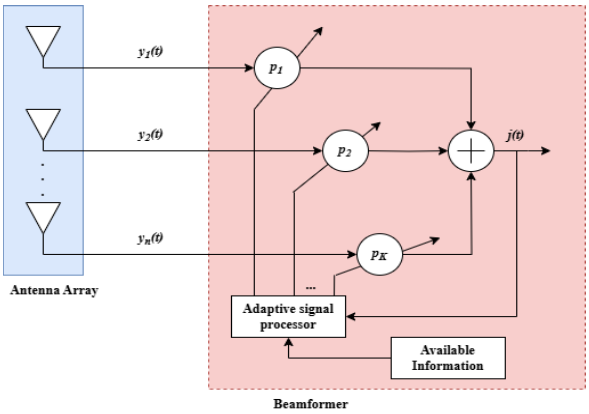

Fig. 1: Smart Antenna Array system

capacity, the amount of data that can be achieved, and the range and coverage of wireless networks, among other benefits. This holds tremendous promise for resolving the shortcomings of these systems. The base station of third-generation wireless mobile networks uses smart antennas to pick up signals from mobile users within the cell. One term for this procedure is the direction-of-arrival (DOA) estimate. The antenna array and adaptive beamformer are the building blocks of a smart antenna system, as shown in Figure 1. To create a directed radiation pattern, an antenna array uses two or more antenna components that are electrically coupled and organized in a certain spatial pattern. In contrast, the adaptive beamformer controls the array pattern in real time to create a beam pattern that boosts power in the directions of detected mobile users and reduces it in the direction of unwanted signals caused by co-channel interference from nearby cells. Due to the lack of specified standards and restrictions, researchers are investigating potential 6G frequency ranges. To address 6G's specifications, however, researchers are looking at some possible frequency ranges. 6G will reportedly use terahertz frequencies, which fall between a few THz and several hundred GHz. Data speeds and capacities are both greatly enhanced by these very high frequencies. Nevertheless, technological hurdles still exist when designing antennas and propagating signals at terahertz frequencies. The technology uses millimeter-wave frequencies (mmWave) over 100 GHz, like 5G, to provide huge bandwidths and high data transmission speeds. Millimeter waves may be utilized for HDLANs at lesser distances. 6G may also employ and build upon frequency ranges used by 5G and preceding generations.

The complex process of awarding 6G frequencies and frequency bands requires global coordination among regulatory bodies, standards organizations, and telecom operators. In the following years, 6G frequencies and bands will be defined as research and standards evolve. Beamforming, intelligent arrays, and user-tracking antennas are vital to wireless communications. Using autonomously radiated pieces or individually activatable antenna parts, beamforming antennas direct the electromagnetic stream while actively repositioning the antenna. An adaptive array antenna's numerous freely movable radiating components allow it to generate and guide many beams in each direction. They are always tweaking the beam's parameters to improve detection and propagation. Transmission power efficiency, disruption, and connection reliability were all enhanced using beamforming and client-tracking antennas, which direct a narrow beam at a single user. This technology works regardless of whether the user is roaming. Thanks to these technological innovations, 6G networks can provide mobile phones and programs that are particularly demanding on network resources with fast, low-latency technology access.

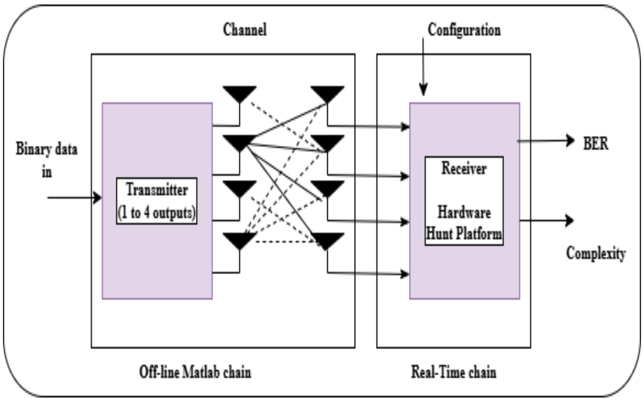

Fig. 2: The framework of Multi-antenna systems

The platform presented in this work uses antenna array methods, which have a much larger computing burden than prior references. However, they still meet the real-time requirements of the user equipment's applications. The offline component and the moment chain are visible in the system, as shown in Figure 1. The receiver is implemented in hardware to address real-time needs, while the channel and transmitter are modelled offline. Users can choose the equipment type, factors, instance, and input/output formats through an intuitive user interface (GUI). System types include single-antenna (SISO), multiple-input/multi-output (SIMO) at the recipient (in the frequency or moment field), and multiple-input/multi-output (MIMO) between the sender and the receiver. An administrator is responsible for operations planning and loading the relevant treatments into the proper DSP. Complexity and performance metrics may be used to assess the results. This study's key areas of emphasis are DSP task scheduling and complexity analysis results.

Each antenna of the Q antenna receiver receives a 12-bit complex digital signal after a CAN converts the real-complex signal. Our sampling frequency returns to HiperLAN/2 after five portions. Additionally, each signal acquired by the Q-meter is presumed to be in perfect sync. In this section, we shall discuss the multi-antenna algorithms in depth. We fine-tune the architecture for each algorithm. A new study suggests that spatio-temporal equalization may potentially provide remarkable results, especially in situations with a wide delay spread channel, even though most approaches concentrate on space-frequency harmonization and filters after the recipient's fast Fourier transformation (FFT). When implementing the hardware platform, both methods are taken into account.

Figure 2 shows a very basic MAAS that uses just one antenna for transmission and reception. On the other hand, the multi-antenna algorithms use that reference chain as a baseline. The duration channel message r(m) is transformed at the destination into a wavelength domain signal using a fast Fourier transform (FFT). The signal is only kept for the parts that help with channel estimate and levelling. Using just the two symbols from the preamble is employed as a least squared (LS) approach to locate the channel and try to keep issues simple. Using an MMSE strategy for each carrier with more received antennas than preceding characters may address the ill-conditioned problem by using legalization approaches, such as diagonally stacking. To solve this problem, the SMI design proposes splitting the band into several groups of subcarriers and using Equation (1) to calculate a unique beamformer for each group:

$$D_x \, p_x = w_x \tag{1}$$

Because the subgroup index is denoted by the subindex. A cross-correlation vector w_x and a correlation matrix are calculated by averaging the OFDM symbols and subcarriers in each group in Equation (2) and (3):

$$D_x = \frac{1}{L_w . R} \sum_{y=0}^{L_w - 1} I_x^F(y) . I_x(y) \tag{2}$$

$$W_x = \frac{1}{L_w . R} \sum_{y=0}^{L_w - 1} I_x^H(y) . \delta_x^F \tag{3}$$

The subcarriers belonging to the nth subgroup are represented by the rows of the I_x (y) matrix, which are snapshot vectors in the frequency domain. The preamble's broadcast signals in the electromagnetic range and the th subgroup are included in the row vector. It should be noted that the cross-correlation vector and correlation matrix are averaged over time (along the subcarriers that make up the same group) and frequency (during the preamble symbols). Not only does this fix the ill-conditioning issue, but it also simplifies things. An issue arises as the groups get larger; beamformers become less tailored to each carrier, compromising both the beamformer's optimality and the stability of the estimates. Due to the absence of specialization, equalization is required after applying these beam vectors during the payload. To avoid getting too technical, the Q antenna's frequency-domain bandwidth is calculated using a fast Fourier transform of a time-domain estimate of an LS channel. Hence, after 4 microseconds, the received symbol is finally acquired.

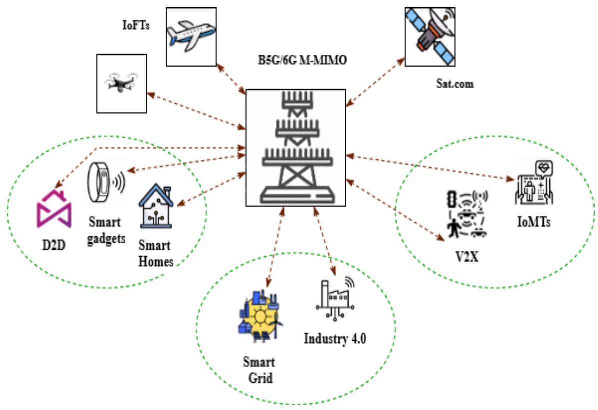

Fig. 3: Multiple Antenna Array in (B5G/6G) Networks

Further improved connections, 5G and 6G, will be available soon. Big multiple-input multiple-output (M-MIMO) networks are a new idea necessary to achieve these lofty goals. Sophisticated Multiple-Input: A revolutionary wireless access technology, Multiple-Output (M-MIMO), can manage the world's data demand, which is increasing exponentially. Low processing complexity and efficient power consumption are possible with a few smart antennas on the broadcast and receive sides. Figure 3 shows the wide variety of technologies that can be easily integrated with M-MIMO. The Vehicle-to-Everything (V2X) network, IoFTs, IoMTs, electric grids, connected instruments, intelligent residences, cell phones, businesses, and observatories are all related to the Internet of Things.

With multi-antenna technologies (MIMO), many information packets may be sent and received in the same radio frequency spectrum simultaneously, making it possible to obtain content across airwaves. Both inside and outdoors, traditional MIMO and M-MIMO processing, precoding, and antenna selection techniques function admirably for 5G services and workplaces. In the future of 6G mobile service platforms, traditional antenna technology will not be enough to handle the ever-increasing data demands. There will be a clear need to enhance precoding/

decoding methods, signal assessments, and calculation efficiency to address many new instances where delays are a factor. The wireless ecosystem stands to gain from merging old and new technologies as 6G builds upon the protocols and architecture of 5G. This is because human-centric mobile network design was the initial target of classical multiplexing approaches. Due to the widespread integration of intelligent nodes into small cell sites and the eventual widespread availability of wireless connectivity, machine/user-centric phone companies will no longer be satisfied with standard duplicating approaches. This is due to two factors: (i) issues with the Rx node's computational complexity for signal recognition and (ii) the design of the formation matrices. Many scientists are looking at the seemingly unorthodox method of manipulating RF propagation properties to uncover new, useful techniques to access radio communication, which goes against common opinion. Prior studies investigated environmental factors such as meta-surfaces, building facades, signs, the refractive index, and the propagation of RF signals (radio frequencies) as potential means to enhance practical productivity and quality of experience (QoS). New index modulation systems, including quadrature, beam, spatial scattering, and media-based modulation, are being developed using this paradigm. These systems primarily use adaptive antennas and additional bits of knowledge on the receiving end according to heavy bouncing conditions to improve the signal quality at the target location. Current systems use strict spectrum resource allocation and management with a diverse range of low-intensity energy-transfer antenna modules to enhance electric power efficiency. It provides versatility, makes interference less likely, and ensures the user has continual, uninterrupted coverage no matter where they are. There is a growing demand for reliable and fast wireless communication, and the advent of B5G and 6G technologies might bring about major advancements in this area. Among these innovations, M-MIMO is reshaping the wireless sector. Improved network performance via dynamic adaptation to changing scenarios and user demands is shown by integrating reconfiguration of intelligent surface (RIS)-based M-MIMO systems (Figure 3). By manipulating radio waves, M-MIMO improves transmission and spectral productivity using neural networks and machine learning approaches. Newer versions of M-MIMO that enhance connectivity and throughput in other contexts include daylight interactions, multimodal beamforming, and multifaceted beam shaping. The uncharted terahertz band allows for fast data transfer, opening up new opportunities for wireless backup and shared multiple-input multiple-output (M-MIMO).

Due to a reuse strategy, several cells share the same frequencies in a certain coverage region. A related phenomenon, co-channel interference, occurs in these cells, which are referred to as co-channel cells. No amount of boosting the transmitter's signal strength will eliminate the issue of co-channel interference for the simple reason that interference in co-channel cells grows in proportion to the SNR at the transmitter. It is possible to reduce cross-channel interference by isolating co-channel cells enough. Cell radius () and distance between nearest co-channel cells () determine the co-channel interference ratio when all base stations employ equal watts and cells have equal dimensions. Therefore, the ratio is used to improve the capacity and quality of transmission, and it is provided in Equation (4).

$$Q = \frac{S}{H} = \sqrt{3X} \tag{4}$$

where is the size of the cell cluster, and is the percentage of co-channel reuse. Improvements in signal transmission quality and reductions in co-channel interference are associated with increasing the value of . Furthermore, the capacity increases as the cluster size decreases. It is also possible to get the signal-to-interference ratio or , using Equation (5).

$$\frac{D}{N} = \frac{D}{\sum_{n=1}^{n_0} N_n} \tag{5}$$

Here, represents the number of interfering co-channel cells, stands for the intended signal strength from the base station of choice, and is the interference power produced by the th base station that is interfering with the signal. Similarly, Equation (6) gives the average received power.

$$W_e = W_0 \left(\frac{r}{r_0}\right)^{-x} \tag{6}$$

Where is the loss exponent and is the received power at a modest distance from the broadcasting antenna.

Results and Discussions

The bandwidth is increased due to these changes to the system's responsiveness. This finding proves the system can effectively transmit signals over a broader spectrum of frequencies. The patch broadens the system's operating frequency range, allowing for greater data rate signal transmission. As predicted, increasing the parallel components resulted in a higher realized gain. Eight parallel components were selected from the many conceivable configurations because they provide the largest gain while avoiding interference with the power connection. The finding suggests that a 6G antenna allows direct signal strength delivery, increasing the transmission range.

Dataset Description: The need for sophisticated antenna systems is growing in tandem with the popularity of autonomous vehicles. Vehicles and their environments can communicate via these technologies, making transportation safer and more efficient. The eCall technology is designed to make roadways safer for everyone by automatically contacting emergency services in case of an accident. The importance of antenna modules in facilitating autonomous driving technology and sophisticated driver-assistance systems will grow as the car industry develops [22]. It also thoroughly examines the market's development, trends, and problems. In addition, the research covers market statistics from 2018 to 2022.

BER Vs SNR:

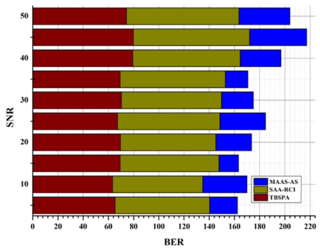

Fig. 4: BER Vs SNR

The BER curve for co-located antenna arrays is also shown for =1, 2, and 3 for comparison's sake. Scattered arrays provide superior BER performance compared to co-located antenna arrays, especially when dealing with more data streams. The BER performance of dispersed or co-located antenna arrays improves as lower. Corollary 1 indicates that scattered antenna arrays provide larger diversity gains than co-located antenna arrays; hence, these observations are predicted and correspond to that. To confirm the accuracy of the diversity gain result provided in sequel 1, Figure 4 displays the diversity gain verifying (GDV) curves generated by the simulation of the GSC systems. The high portion of a BER curve and the matching SNR curve are the same in slope, regardless of whether the antenna arrays are spread or co-located.

Efficiency:

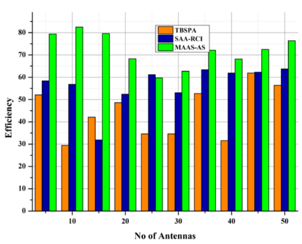

Fig. 5: Efficiency

With the antenna's improved directivity at this high frequency, the signal may be effectively sent in a given direction (See Figure 5). The concentrated and narrow beam made a longer transmission range possible, allowing for long-distance communication. There were fewer disturbances with nearby gadgets and communications because of the irradiation pattern's robust side loop suppression. With its 145 GHz 6G antenna, situations necessitating simultaneously far-reaching connectivity and fast speeds could be adequately met. The results show that a 6G antenna may increase its communication range by directing the supply of signal intensity, as shown in Figure 5. The antenna also worked well, reducing interference and ensuring power economy. Based on these simulation findings, this antenna might be a good fit for 6G and other high-frequency transmission applications that need very high data rates.

Improved Precision:

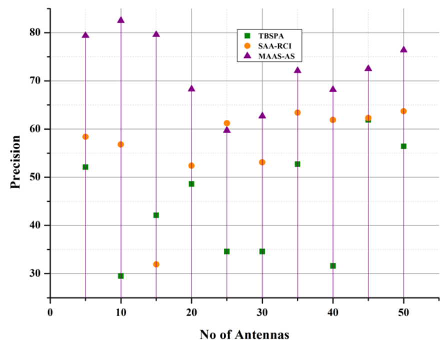

Fig. 6: Precision

Production methods that are inexpensive, accurate, and dependable have a significant impact on the advancement of THz band antennas. Another challenge with THz band antennas is their diminutive size, which makes them hard to design and test. At such frequencies, the increased insertion loss induced by substantial surface imperfections renders conventional production methods utilized for most millimetre waves and wireless antennas ineffective. It is since producing antennas for the THz band necessitates high precision, compassion, and flawless finish on the exterior. The THz band antenna can only be mass-produced within certain parameters, as seen in Figure 6. For the time being, THz band antennas can only be mass-produced for frequencies up to 1 THz.

Conclusion

For frequencies higher than 1 THz, there is no publicly available manufacturing process for antennas. The installation and cost of the antenna are both affected by this; therefore, This remains an unresolved scientific matter that must be addressed later. The same holds true for the THz band antenna monitoring; at this time, no antenna measurement equipment (such as vector network analyzers) can handle frequencies over 1 THz. Accuracy is difficult to achieve with the THZ band antenna due to its high cost and complex alignment and deployment process. Concerning the measuring procedures and the price of the antenna, this is another unresolved area of study that will need future attention. Two safe and accurate techniques with many carriers were suggested based on a model for autonomous systems' transmission that uses numerous arrays of antennas at the sending end and a mixing board at the receiving end. These results demonstrate that a dependable and high-performance 6G network cannot be established without millimeter-wave antennas. The advancements in this area pave the way for new possibilities in wireless networking, such as very low latency, vast coverage, and enormous data rates. In addition, these 6G antenna design innovations might usher in a new era of wireless communications and open the door to groundbreaking new applications and services. To fulfil the future needs of connection and take advantage of the potential given by 6G technology, it is essential to keep researching and creating new approaches and solutions. Ultimately, this study substantially adds to the literature on 6G antennas.

According to the simulation findings, the suggested approaches outperform a Multiple Antenna Array regarding neighbor security and accurate transmission. Adding support for many users and eavesdroppers over several fading paths is also intriguing. Additionally, it is highly recommended that the sturdy designs of the offered systems be considered. Researching and validating the security performance of the suggested approaches in real-world communication settings is one area that needs attention for future development. According to these results, millimeter-wave antennas are crucial for setting up a 6G network that is both dependable and very fast. New possibilities for wireless communication, such as very low latency, vast coverage, and enormous data rates, have emerged due to advancements in this area. In addition, these 6G antenna design innovations might potentially usher in a new era of wireless communications and open the door to groundbreaking novel services and apps. To make the most of the opportunities, it is crucial to maintain studying and developing new approaches and solutions given by 6G technology and satisfy the future needs for connection. Finally, regarding 6G antenna research, the present study is a major step forward.

References

1. López-Pastor, J. A., Gil-Martinez, A., Muñoz, G. I., & Gómez-Tornero, J. L. (2024, October). Real-Time Location Landing Autonomous System Using WiFi Antennas for UAVs. In *2024 14th International Conference on Indoor Positioning and Indoor Navigation (IPIN)* (pp. 1-6). IEEE.
2. Lemay, D. J., Basnet, R. B., & Doleck, T. (2020). Examining the Relationship between Threat and Coping Appraisal in Phishing Detection among College Students. *Journal of Internet Services and Information Security*, *10*(1), 38-49.
3. Ibrahim, A. S., Yacoub, A. M., & Aloi, D. N. (2022). A 3-dimensional multiband antenna for vehicular 5G sub-6 GHz/GNSS/V2X applications. *International Journal of Antennas and Propagation*, *2022*(1), 5609110.
4. 16. Miyaji, A., Rahman, M.S., & Soshi, M. (2011). Efficient and low-cost RFID authentication schemes. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 2(3), 4-25.
5. Sun, Y., Liu, J., Zhang, J., Wang, A., & Mao, F. (2022). Chaos of the Six-Dimensional Non-Autonomous System for the Circular Mesh Antenna. *Mathematics*, *10*(23), 4454.
6. Esmaeil Nik Maleki and Ghasem Mirjalily. (2015). Step by Step Methodology for Implementation of the Telephony Services on Data Networks. International Academic Journal of Science and Engineering, 2(2), 121–145.
7. Borghesan, F., Zagorowska, M., & Mercangöz, M. (2022). Unmanned and autonomous systems: Future of automation in process and energy industries. *IFAC-PapersOnLine*, *55*(7), 875-882.
8. Uvarajan, K. P. "Integration of Blockchain Technology with Wireless Sensor Networks for Enhanced IoT Security." Journal of Wireless Sensor Networks and IoT 1.1 (2024): 15-18.
9. Zhang, X., Kwon, K., Henriksson, J., Luo, J., & Wu, M. C. (2022). A large-scale microelectromechanical-systems-based silicon photonics LiDAR. *Nature*, *603*(7900), 253-258.
10. Sadulla, Shaik. "State-of-the-Art Techniques in Environmental Monitoring and Assessment." Innovative Reviews in Engineering and Science 1.1 (2024): 25-29.
11. Costanzo, A., Benassi, F., & Monti, G. (2022). Wearable, energy-autonomous RF microwave systems: Chipless and energy-harvesting-based wireless systems for low-power, low-cost localization and sensing. *IEEE Microwave Magazine*, *23*(3), 24-38.
12. Kumar, TM Sathish. "Integrative Approaches in Bioinformatics: Enhancing Data Analysis and Interpretation." Innovative Reviews in Engineering and Science 1.1 (2024): 30-33.
13. Venkatesh, S., Lu, X., Saeidi, H., & Sengupta, K. (2022). A programmable terahertz metasurface with circuit-coupled meta-elements in silicon chips: creating low-cost, large-scale, reconfigurable terahertz metasurfaces. *IEEE Antennas and Propagation Magazine*, *64*(4), 110-122.

14. Abdullah, Dahlan. "Enhancing Cybersecurity in Electronic Communication Systems: New Approaches and Technologies." Progress in Electronics and Communication Engineering 1.1 (2024): 38-43.
15. Gyagenda, N., Hatilima, J. V., Roth, H., & Zhmud, V. (2022). A review of GNSS-independent UAV navigation techniques. *Robotics and Autonomous Systems*, *152*, 104069.
16. Ullah, M. A., Keshavarz, R., Abolhasan, M., Lipman, J., Esselle, K. P., & Shariati, N. (2022). A review on antenna technologies for ambient RF energy harvesting and wireless power transfer: Designs, challenges and applications. *IEEE Access*, *10*, 17231-17267.
17. Bryant, B., Won, H., Hong, Y. K., Lee, W., & Choi, M. (2022). Design of Triple-Band (DSRC, 5G, 6G) Antenna for Autonomous Vehicle Telematics. *Electronics*, *11*(16), 2523.
18. Hong, T., Lv, M., Zheng, S., & Hong, H. (2021). Key technologies in 6G SAGS IoT: Shape-adaptive antenna and radar-communication integration. *IEEE Network*, *35*(5), 150-157.
19. Siddiqui, M. U. A., Qamar, F., Kazmi, S. H. A., Hassan, R., Arfeen, A., & Nguyen, Q. N. (2022). A study on multi-antenna and pertinent technologies with AI/ML approaches for B5G/6G networks. *Electronics*, *12*(1), 189.
20. Xiao, Z., Han, Z., Nallanathan, A., Dobre, O. A., Clerckx, B., Choi, J., ... & Tong, W. (2022). Antenna array enabled space/air/ground communications and networking for 6G. *IEEE Journal on Selected Areas in Communications*, *40*(10), 2773-2804.
21. Guo, Y. J., Ansari, M., Ziolkowski, R. W., & Fonseca, N. J. (2021). Quasi-optical multi-beam antenna technologies for B5G and 6G mmWave and THz networks: A review. *IEEE Open Journal of Antennas and Propagation*, *2*, 807-830.
22. https://datasetsearch.research.google.com/search?src=0&query=Antennas%20for%20autonomous%20systems&docid=L2cvMTF3cGxobHI2Xw%3D%3D
23. Kraus, D., Diwold, K., Pestana, J., Priller, P., & Leitgeb, E. (2022). Towards a recommender system for in-vehicle antenna placement in harsh propagation environments. *Sensors*, *22*(17), 6339.
24. Owais, M., Midtiby, H., Trifon, D., & Hasan, A. (2022, June). Autonomous Drone-Based Antenna Radiation Pattern Characterization. In *2022 International Conference on Unmanned Aircraft Systems (ICUAS)* (pp. 207-213). IEEE.
25. Mir, I., Gul, F., Mir, S., Khan, M. A., Saeed, N., Abualigah, L., ... & Gandomi, A. H. (2022). A survey of trajectory planning techniques for autonomous systems. *Electronics*, *11*(18), 2801.
26. Subitha, D., Velmurugan, S., Lakshmi, M. V., Poonkuzhali, P., Yuvaraja, T., & Alemayehu, S. (2022). Development of Rogers RT/Duroid 5880 Substrate-Based MIMO Antenna Array for Automotive Radar Applications. *Advances in Materials Science and Engineering*, *2022*(1), 4319549.
27. Hawkins, R., Osborne, M., Parsons, M., Nicholson, M., McDermid, J., & Habli, I. (2022). Guidance on the safety assurance of autonomous systems in complex environments (SACE). *arXiv preprint arXiv:2208.00853*.
28. Motroni, A., Bernardini, F., Buffi, A., Nepa, P., & Tellini, B. (2022). A UHF-RFID multi-antenna sensor fusion enables item and robot localization. *IEEE Journal of Radio Frequency Identification*, *6*, 456-466.
29. Rana, M. S., Islam, S. I., Al Mamun, S., Mondal, L. K., Ahmed, M. T., & Rahman, M. M. (2022). An S-band microstrip patch antenna design and simulation for wireless communication systems. *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, *10*(4), 945-954.
30. Barhoumi, E. M., Charabi, Y., & Farhani, S. (2024). Detailed guide to machine learning techniques in signal processing. Progress in Electronics and Communication Engineering, 2(1), 39–47. https://doi.org/10.31838/PECE/02.01.04
31. Lucena, K., Luedeke, H. J., & Wirth, T. (2025). The evolution of embedded systems in smart wearable devices: Design and implementation. SCCTS Journal of Embedded Systems Design and Applications, 2(1), 23–35.
32. William, A., Thomas, B., & Harrison, W. (2025). Real-time data analytics for industrial IoT systems: Edge and cloud computing integration. Journal of Wireless Sensor Networks and IoT, 2(2), 26-37.
33. Mia, M., Emma, A., & Hannah, P. (2025). Leveraging data science for predictive maintenance in industrial settings. Innovative Reviews in Engineering and Science, 3(1), 49-58. https://doi.org/10.31838/INES/03.01.07
34. Frincke, G., & Wang, X. (2025). Hardware/software co-design advances for optimizing resource allocation in reconfigurable systems. SCCTS Transactions on Reconfigurable Computing, 2(2), 15–24. https://doi.org/10.31838/RCC/02.02.03
35. Madhushree, R., Gnanaprakasam, D., Kousalyadevi, A., & Saranya, K. (2025). Design and development of two stage operational trans-conductance amplifier with single ended output for EEG application. Journal of Integrated VLSI, Embedded and Computing Technologies, 2(1), 62–66. https://doi.org/10.31838/JIVCT/02.01.08