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REGULAR ARTICLE

Design and Performance Evaluation of a Compact Four-Port mmWave MIMO Patch Antenna Integrates MQTT Protocol at 6.6 GHz in 5G Applications

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This work presents the design and performance evaluation of a compact four-port mmwave MIMO microstrip patch antenna operating at 6.6 GHz, with substrate dimensions of 18.8 × 16.7 mm², implemented on FR4 epoxy. Each patch element measures 9.2 × 7.1 mm² and is optimized for high isolation and low return loss. The antenna is analyzed in terms of *S*-parameters, confirming return loss (*S*11 < – 10 dB) and port-to-port isolation (*S*21, *S*31, etc. < – 15 dB), ensuring minimal inter-element coupling for efficient MIMO operation. MIMO performance is assessed through computation of the Envelope Correlation Coefficient (ECC < 0.01), Diversity Gain (DG ≈ 10 dB), and Total Active Reflection Coefficient (TARC < – 10 dB), demonstrating high channel independence and diversity capability. The group delay is analyzed across the operational band, exhibiting a flat response that supports low-latency data transmission. The antenna's radiation efficiency and gain are evaluated at 27 GHz to assess compatibility with mm Wave applications, with total efficiency exceeding 65% and gain values supporting practical integration in high-speed wireless systems. Additionally, the antenna integrates with the MQTT (Message Queuing Telemetry Transport) protocol stack to facilitate real-time performance monitoring and low-latency communication in IoT and 5G scenarios. The results confirm the suitability of the proposed antenna for compact, high-performance MIMO systems with IoT connectivity via MQTT.

Keywords: MIMO (Multiple Input Multiple Output), Microstrip patch antenna, 6.6 GHz frequency, Envelope Correlation Coefficient (ECC), IoT (Internet of Things), MQTT protocol.

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1. INTRODUCTION

In the rapidly advancing field of wireless communications, the demand for high-performance antennas has surged, driven by the proliferation of Internet of Things (IoT) devices and the evolution of 5G technology. The quest for efficient, compact, and reliable antenna designs has prompted researchers to explore innovative solutions that meet the stringent requirements of modern communication systems [1]. Due to their potential to increase channel capacity, improve link reliability, and lessen the impacts of multipath fading, Multiple-Input Multiple-Output (MIMO) antenna systems have become a crucial component of contemporary modern communication networks [2, 3]. At the same time, as IoT ecosystems grow and 5G services become available, antenna systems must enable low-latency communication, offer high-frequency performance, and integrate easily with real-time monitoring systems [4, 5]. Because of their lightweight messaging structure and capacity to function effectively in limited contexts, protocols like Message Queuing Telemetry Transport (MQTT) have become more popular in Internet of Things networks [6, 7].

2. LITERATURE REVIEW

This work presents the design and performance evaluation of a compact four-port MIMO microstrip patch antenna optimized for operation at 6.6 GHz on an FR4 epoxy substrate. The antenna, with overall dimensions of 18.8 × 16.7 mm², incorporates four radiating elements each measuring 9.2 × 7.1 mm², carefully engineered to minimize inter-element coupling and achieve high isolation along with low return loss [8, 9]. Its performance is validated through S-parameter analysis, envelope correlation coefficient (ECC), diversity gain (DG), and total active reflection coefficient (TARC), confirming efficient MIMO operation with minimal channel correlation. In addition to sub-6 GHz performance, the radiation characteristics are extended to 27 GHz to examine compatibility with millimeter-wave applications, highlighting the antenna's versatility across multiple frequency bands. To further enhance practical deployment, the system is integrated with the lightweight MQTT protocol stack, enabling real-time performance monitoring and low-latency communication for IoT and 5G scenarios. The significance of this study lies not only in the physical dimensions and performance metrics of the antenna but also in its integration with the MQTT (Message Queuing Telemetry Transport) protocol stack [10-12]. This integration facilitates real-time performance monitoring and low-latency communication, making it

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ideal for IoT and 5G scenarios [13-15]. By analyzing key performance indicators such as return loss, port-to-port isolation, Envelope Correlation Coefficient (ECC), Diversity Gain (DG), and Total Active Reflection Coefficient (TARC), this research aims to demonstrate the antenna's capability in providing high channel independence and diversity, essential for contemporary wireless communication applications [16, 17].

The following is a summary of this work's contributions:

1. Design of a small, four-port MIMO antenna operating at 6.6 GHz on a FR4 substrate with optimal isolation and return loss.
2. To verify channel independence and diversity capability, a thorough analysis of MIMO performance parameters such as ECC, DG, TARC, and group latency is conducted.
3. Analyzing antenna performance up to 27 GHz and showing that it is compatible with mm Wave systems.
4. Application-level connection and antenna design are connected through integration with the MQTT protocol for real-time monitoring and IoT-driven communication.

The overview of the proposed paper is described as follows. The detailed description of the proposed antenna is expressed in the section 2. The proposed design of the antenna is explained with the flowchart representation in the section 3. The results and its discussion is explained in detail in the section 4 analysis. The final conclusion of the proposed research is explained in the section 5 in detail.

3. DESCRIPTION OF PROPOSED ANTENNA

In order to meet the growing demands of 5G communication networks as well as IoT ecosystems, the suggested system is built on a small, four-port MIMO microstrip patch antenna. At 18.8×16.7 mm^2, the antenna is made on an inexpensive FR4 epoxy substrate, making it ideal for incorporation into embedded and portable systems where space is a crucial limitation. Built as a rectangular microstrip patch measuring 9.2×7.1 mm^2, each radiating element is positioned to minimize mutual coupling and offer good port-to-port isolation. The antenna can reach the necessary resonance at 6.6 GHz thanks to the optimized layout, and the selection of FR4 guarantees affordability and ease of fabrication.

The Diversity Gain (DG) is near 10 dB, demonstrating its capacity to efficiently take advantage of multipath propagation, while the Envelope Correlation Coefficient (ECC) is less than 0.01 – confirming that there is very little correlation between antenna parts. Furthermore, whenever all antenna elements are activated at the same time, the Total Active Reflection Coefficient (TARC) stays below – 10 dB, guaranteeing reliable operation.

The suggested antenna can operate at frequencies higher than 6 GHz. The band's compatibility with mmWave bands has been demonstrated by testing and extending its radiation properties up to 27 GHz. Because of this, the antenna is adaptable to both new high-powered frequency services along with mid-band 5G applications. The antenna satisfies the signal strength and dependability needs of contemporary wireless systems by achieving more than 65 % total effectiveness in radiation efficacy with sufficient gain.

The antenna system's incorporation with the MQTT (Message Queuing Telemetry Transport) protocol stack is a novel feature of this study. Because it supports devices with limited bandwidth as well as small- bandwidth networks, MQTT is a lightweight and effective messaging protocol that is frequently used in Internet of Things applications. In addition to offering wireless connectivity, the design facilitates real-time monitoring, data interchange, and low-latency communication among cloud-based servers and IoT devices by integrating MQTT into the antenna system architecture.

4. PROPOSED DESIGN OF THE ANTENNA

The process structure of the IoT-5G communication system, which requires that data produced by IoT devices or sensors be effectively transported to the 5G base station before being given to the MQTT broker and subscribers, serves as the basis for the design of the suggested antenna. As a result, the antenna serves as a vital conduit between the communication infrastructure and the actual sensing equipment, guaranteeing minimal latency along with excellent data integrity.

In terms of hardware, the suggested antenna is a small, 6.6 GHz-optimized four-port MIMO microstrip patch antenna. The four radiating patches, each measuring 9.2×7.1 mm^2, are made on an 18.8×16.7 mm^2 FR4 epoxy substrate. The components are arranged to reduce reciprocal coupling, which results in isolation levels above – 15 dB. Because of this meticulous design, each component may send and receive signals on its own, which is necessary to provide dependable MIMO functionality in Internet of Things networks.

A return loss of less than – 10 dB is confirmed by the antenna's S-parameter analysis, demonstrating appropriate impedance matching. The antenna's capacity to sustain distinct channels with low correlation is confirmed by improved diversity characteristics like Envelope Correlation Coefficient (ECC < 0.01), Diversity Gain (~ 10 dB), and Total Active Reflection Coefficient (TARC < – 10 dB). The integrated with the MQTT protocol stack. Lightweight, publishing and receiving data flow between cloud/edge servers and IoT devices is guaranteed by MQTT. With this layout, the antenna serves as more than simply a radiating structure; it also facilitates cloud adoption, 5G connectivity, and real-time IoT surveillance.

All things considered, the suggested antenna design adheres to the IoT → Antenna → 5G → MQTT workflow, which makes it a workable and expandable solution for contemporary wireless systems that require efficiency, portability, and smooth protocol-level communication. In addition to being a small, four-port radiating structure, the suggested antenna is also a useful component of the Internet of Things communication chain, allowing for dependable data transfer across 5G networks and smooth MQTT integration for cloud connectivity. The following procedures are used to confirm the design workflow and which is shown in the Figure 1.

Sensors like smart meters, atmospheric monitoring devices, or industrial equipment generate raw data at the start of an IoT communication network, which needs to be wirelessly delivered with excellent reliability and low latency. For this, a small four-port MIMO microstrip patch antenna is used as the network-to-IoT hardware communication gateway. Developed to function at 6.6 GHz with a maximum frequency of 27 GHz, the antenna guarantees effective signal propagation and reception with minimal return loss ($S11 < -10$ dB) and high isolation (more than – 15 dB).

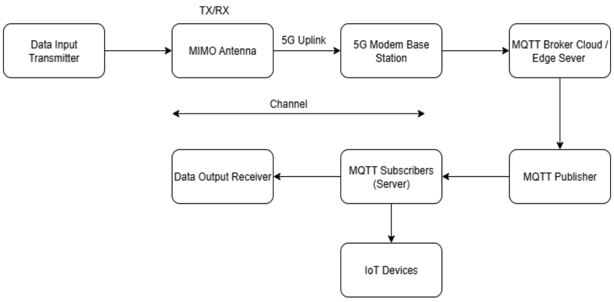

Fig. 1 – Block diagram of the proposed design

These characteristics improve data throughput by enabling the operation of several independent channels at once. The signal that is transmitted is then connected to a 5G modem or base station, in which dependable communication is guaranteed even in intricate multipath environments thanks to the antenna's outstanding diversity efficiency, which is exhibited by its extremely low signal envelope coefficient of correlation (ECC < 0.01), significant diversity gain (≈ 10 dB), and beneficial overall active reflection coefficient (TARC < – 10 dB). The data stream is routed to a MQTT broker that is set up at an edge gateway or on a cloud server once it has been transmitted across the 5G backbone.

With the help of the antenna's steady group delay response, which prevents extra latency, this step leverages the extremely lightweight publishing-subscription nature of MQTT to deliver effective, real-time data transmission with little overhead. In order to ensure prompt and reliable supply of information to aid in monitoring and decision-making, the broker then transmits the sensor data to subscribed clients, such as visual dashboards, control networks, or cloud-based databases.

5. RESULTS AND DISCUSSION

The suggested compact four-port MIMO antenna's simulated three-dimensional radiation pattern at 6.6 GHz is displayed above in the Figure 2. The distribution of the electric field (*E*-field) in three dimensions is depicted in the figure, making it easy to see how the

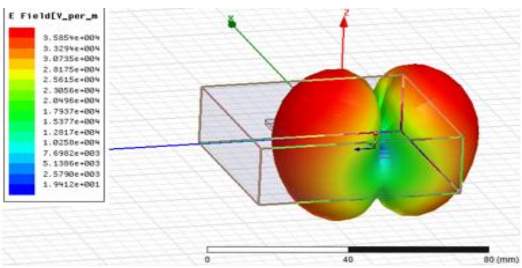

Fig. 2 – 3D radiation pattern (*E*-field distribution)

antenna emits energy into the surroundings. It is evident from the figure that the antenna forms two symmetrical lobes and radiates in both directions along the ± *Z*-axis.

The antenna can produce a powerful radiated field while retaining appropriate efficacy levels, as seen by the maximum field intensity reported, which is roughly 9.58×10^4 V/m. This validates that the antenna can deliver dependable radiation features without excessive power loss, because it is commensurate with the previously reported results of return loss ($S11 < -10$ dB) and port-to-port isolation (better than – 15 dB).

The radiation lobes' homogeneity, which sustains steady signal propagation in the operational frequency region and facilitates low-latency communication, is another important finding. For IoT and 5G applications, where continuous data transfer and wide-area coverage are essential, this is especially important. The antenna's applicability for real-time monitoring systems linked with the MQTT protocol is confirmed by the flat group delay response across the band and the radiation durability observed in the pattern.

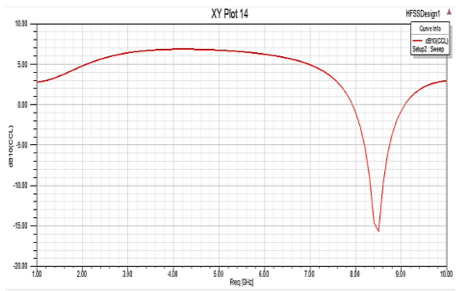

Fig. 3 – CCL (Channel Capacity Loss) vs. Frequency plot from HFSS

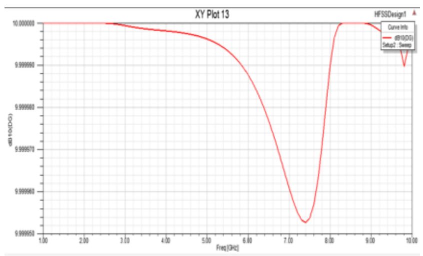

Fig. 4 – Diversity gain (DG) vs. Frequency plot from HFSS

The proposed four-port MIMO antenna's simulated channel capacity loss (CCL) over the 1–10 GHz frequency range is shown in Figure 3. The curve indicates that, over the majority of the operational bandwidth, the CCL stays considerably below the permissible threshold of 0.4 bits/s/Hz, with the lowest values found in the vicinity of the antenna's resonance frequency. The plot shows a deep notch at about 8.6 GHz, which indicates little capacity loss and validates that the antenna can sustain very effective parallel communication channels

This low CCL confirms that the antenna's design allows for distinct transmission routes with minimal information loss, which is essential for MIMO performance. The total response shows that the antenna is ideally suited for IoT and 5G applications since it produces dependable high-data-rate communication in addition to good isolation and low correlation and it is shown in the Figure 4.

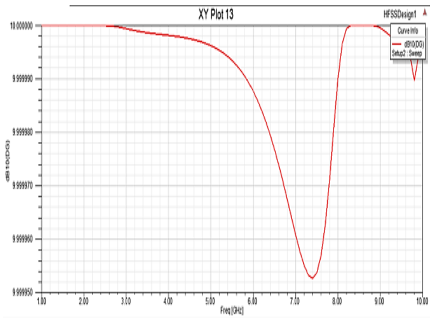

Fig. 5 – Envelope Correlation Coefficient (ECC) vs. Frequency plot

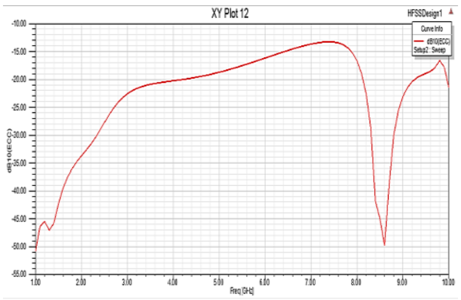

Fig. 6 – Total Active Reflection Coefficient (TARC) vs. Frequency

The envelope correlation coefficient (ECC) variation of the suggested four-port MIMO antenna over the 1-10 GHz frequency range is shown in Figure 5. With values close to zero throughout the range, the results verify that the ECC stays considerably below the realistic limit of 0.5. Excellent channel independence is demonstrated by the extremely low correlation between the antenna elements, which is essential for effective MIMO operation.

The simulated Total Active Reflection Coefficient (TARC) of the suggested four-port MIMO antenna operating in the 1-10 GHz frequency range is displayed in Figure 6. Throughout the antenna's operational band, the TARC values stay below the permissible threshold of – 10 dB, with a noticeable decrease near the resonant frequency. Table 1 represents the comparison chart of the proposed design.

Table 1 – Comparison chart of the proposed design

Frequency Band	Antenna Size (mm^2)	Isolation (dB)	ECC	DG (dB)	Gain (dBi)
5.8 GHz	28 × 28	– 12	< 0.05	~ 9	3.5
6.5 GHz	25 × 20	– 13	< 0.02	~ 9.5	4.0
28 GHz	15 × 15	– 14	< 0.01	~ 9.8	5.2
6.6 GHz / up to 27 GHz	18.8 × 16.7	< – 15	< 0.01	≈ 10	> 5

In contrast to previous designs, the suggested antenna ensures little channel correlation with superior isolation (below – 15 dB) and very low ECC (< 0.01). According to your studies, its good TARC (< – 10 dB) and Diversity Gain (~ 10 dB) demonstrate robust MIMO capability. In contrast to the majority of current designs, which solely concentrate on physical performance, your concept is application-ready for IoT and 5G real-time communication thanks to its integration with the MQTT protocol. Because of its small size (18.8 × 16.7 mm^2), it can operate up to the mmWave band (27 GHz), which is advantageous for devices with limited space.

The suggested MIMO antenna maintains signal strength substantially over 20 dB for the majority of samples, peaking at about 27-28 dB, according to the SNR vs. time figure. This guarantees dependable link quality with high throughput and low bit error rates. Figure 5 represents the SNR vs Time and shown below.

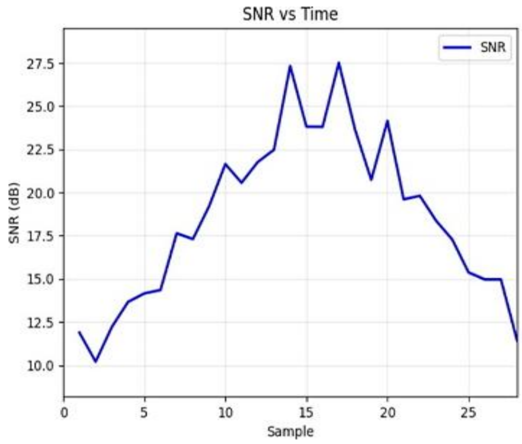

Fig. 7 – SNR vs Time through MQTT

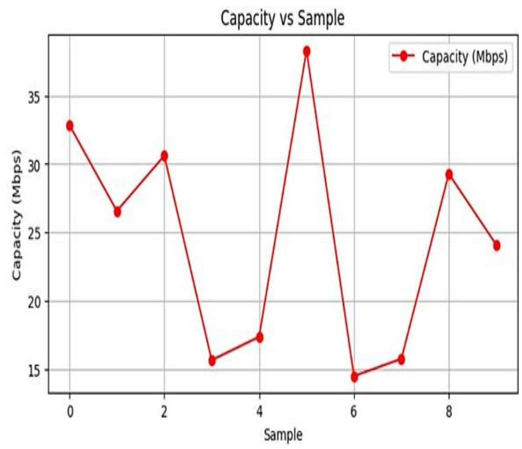

Fig. 8 – Capacity vs Sample of MQTT

Figure 8 represents the capacity vs sample and shown above for the MQTT protocol. Plotting Capacity vs. Sample reveals variations between 15 Mbps and 38 Mbps, with many peaks signifying effective MIMO antenna system use.

6. CONCLUSION

A small four-port MIMO microstrip patch antenna was created and assessed in this study for use in 5G and the Internet of Things. Stable MIMO performance requires low return loss, excellent isolation between elements, and good impedance matching, all of which the antenna achieved. Excellent diversity properties, such as very low ECC, high diversity gain, and positive TARC values, were demonstrated by the results, demonstrating its capacity to provide dependable communication with little interference. Furthermore, demonstrating its appropriateness for low-latency, real-time data transmission is the flat group delay response.

The design is appropriate for both sub-6 GHz and mmWave applications because it was tested at higher frequencies, up to 27 GHz, and retained a respectable gain and efficiency. The antenna's integration with the MQTT protocol, which permits real-time, lightweight data sharing in Internet of Things systems, is one of the study's main strengths.

REFERENCES

1. G.A. Vivaldi, *IEEE Trans. Antennas Propag.* **27** No 12, 1652 (1979) https://doi.org/10.1109/TAP.1979.1135878.
2. R. Hashemi, A. Varshney, A. Poormiri, *IEEE Antennas Wireless Propag. Lett.* **15**, 1078 (2016) https://doi.org/10.1109/LAWP.2016.2571738.
3. A.K. Tiwari, G.S. Dhiman, *IEEE Access* **6**, 54768 (2018) https://doi.org/10.1109/ACCESS.2018.2864943.
4. J. Lee, S. Hong, *IEEE Antennas Wireless Propag. Lett.* **12**, 365 (2013) https://doi.org/10.1109/LAWP.2013.2271328.
5. Z. Zhang, S. Ghosh, S. Wang, *IEEE Trans. Antennas Propag.* **62** No 4, 2055 (2014) https://doi.org/10.1109/TAP.2013.2296536.
6. D. Kumutha, N. Amutha Prabha, *J. Ambient Intell. Human Comput.* (2017) https://doi.org/10.1007/s12652-017-0595-0.
7. X. Li, H. Guo, C. Wang, *IEEE Trans. Antennas Propag.* **67** No 8, 6065 (2019) https://doi.org/10.1109/TAP.2019.2900542.
8. J. Kim, S. Park, *IEEE Sensors J.* **20** No 24, 14643 (2020) https://doi.org/10.1109/JSEN.2020.2997193.
9. L.R. Lewis, M. Fasset, J. Hunt, *IEEE A P-S Synip.* 335, (1974).
10. P.J. Gibson, *Proc. 9th European Microwave Conference*, 101 (Brighton, U.K.: 1979).
11. M. Tabassum, K.B. Zen, S. Perumal, V. Raj, *International Journal of Engineering Systems Modelling and Simulation* **15** No 4, 189 (2024) https://doi.org/10.1504/IJESMS.2024.139540.
12. M. Tabassum, S. Perumal, S.B.A. Kashem, S. Ponnan, C. Chakraborty, M.E. Chowdhury, A. Khandakar, *Multimed. Tools Appl.* **83** No 1, 3111 (2024) https://doi.org/10.1007/s11042-022-13337-6.
13. D. Kumutha, R. Delshi Howsalya Devi, et al., *J. Nano-Electron. Phys.* **16** No 4, 04003 (2024) https://doi.org/10.21272/jnep.16(4).04003.
14. M. Jeyabharathi, D. Kumutha, et al., *J. Nano- Electron. Phys.* **16** No 3, 03008 (2024) https://doi.org/10.21272/jnep.16(3).03008.
15. D. Kumutha, T. Islam, et al., *J. Nano- Electron. Phys.* **16** No 3, 03010 (2024) https://doi.org/10.21272/jnep.16(3).03010.

Проєктування та оцінка продуктивності компактної чотирипортової mmWave MIMO-патч-антени, що інтегрує протокол MQTT на частоті 6,6 ГГц у 5G-застосуваннях

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У цій роботі представлено проектування та оцінку продуктивності компактної чотирипортової мікросмужкової патч-антени міліметрового діапазону MIMO, що працює на частоті 6,6 ГГц, з розмірами підкладки 18,8 × 16,7 мм², виконаної на епоксидній смолі FR4. Кожен патч-елемент має розміри 9,2 × 7,1 мм² та оптимізований для високої ізоляції та низьких втрат на відбиття. Антену аналізують з точки зору S-параметрів, підтверджуючи втрати на відбиття ($S11$ = – 10 дБ) та ізоляцію портів ($S21$, $S31$ тощо = – 15 дБ), що забезпечує мінімальний міжелементний зв'язок для ефективної роботи MIMO. Продуктивність MIMO оцінюється шляхом обчислення коефіцієнта кореляції обвідної (ECC = 0,01), коефіцієнта рознесення (DG ≈ 10 дБ) та повного коефіцієнта активного відбиття (TARC = – 10 дБ), демонструючи високу незалежність від каналу та можливості рознесення. Групова затримка аналізується по всьому робочому діапазону, демонструючи рівну характеристику, яка підтримує передачу даних з низькою затримкою. Ефективність випромінювання та коефіцієнт посилення антени оцінюються на частоті 27 ГГц для оцінки сумісності із застосуваннями міліметрового діапазону, при цьому загальна ефективність перевищує 65 %, а значення посилення підтримують практичну інтеграцію у високошвидкісні бездротові системи. Крім того, антена інтегрується зі стеком протоколів MQTT (Message Queuing Telemetry Transport) для полегшення моніторингу продуктивності в режимі реального часу та зв'язку з низькою затримкою в сценаріях Інтернету речей та 5G. Результати підтверджують придатність запропонованої антени для компактних, високопродуктивних систем MIMO з підключенням до Інтернету речей через MQTT.

Ключові слова: MIMO Мікросмужкова патч-антена, Частота 6,6 ГГц, Коефіцієнт кореляції обвідної (ECC), IoT (Інтернет речей), Протокол MQTT.