ISSN 1840-4855
e-ISSN 2233-0046

Original scientific article
http://dx.doi.org/10.70102/afts.2025.1834.256

BIO INSPIRED RECONFIGURABLE ANTENNA ARRAYS FOR ULTRA-LOW POWER BODY AREA COMMUNICATION NETWORKS

Roohee Khan[1*], Ashu Nayak[2]

[1]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India*
e-mail: ku.roohee.khan@kalingauniversity.ac.in,
orcid: https://orcid.org/0009-0009-8960-8840
[2]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India,
e-mail: ku.ashunayak@kalingauniversity.ac.in,
orcid: https://orcid.org/0009-0009-6363-1591

Received: August 23, 2025; Revised: October 07, 2025; Accepted: November 14, 2025; Published: December 30, 2025

SUMMARY

Bio-inspired reconfigurable antenna arrays may be one possible answer to the challenges of energy efficiency, capability, and stability in ultra-low-power Wireless Body Area Networks (WBANs). In this paper, a bio-inspired reconfigurable architecture for antenna arrays is proposed, which can adaptively change radiation patterns and impedance properties to varying body-centric propagation environments. It is designed to work with wearable and implantable biomedical communications and, in the sub-GHz and ISM frequency bands, will support both applications. Extensive electromagnetic modeling and on-body experimental data are run across multiple user postures and mobility conditions. The findings indicate that the said antenna has shown a radiation efficiency of up to 18% and a link stability of up to 1.5 dB of gain variation, compared with conventional fixed-antenna designs under dynamic body conditions. Specific Absorption Rate (SAR) analysis shows it has decreased by about 22% and remains well below international safety limits. The adaptive reconfiguration scheme enhances communication reliability in non-line-of-sight and body-shadowed environments, improving the packet-delivery ratio by up to 25% at a complementary power penalty of less than 3%, allowing sustained ultra-low-power operation. The statistical results of the repeated-measures analysis of the mobility trials confirm that low-variance gain behavior (standard deviation < 1.2 dB) is the strength of the proposed bio-inspired control strategy. The proposed system-level solution achieves up to 20% improvement in energy efficiency, relative to packet-delivery success, compared with the current WBAN antenna solution in the presence of mobility-induced fading. These findings indicate that bio-inspired reconfigurable antenna arrays are scalable and robust for the next generation of WBANs, enabling reliable health monitoring, long-term implantable communications, and continuous wearable sensing in highly dynamic body-based contexts.

Key words: *bio-inspired antenna design, reconfigurable antenna arrays, wireless body area networks (wbans), ultra-low-power communication, on-body propagation, adaptive beamforming, wearable and implantable devices.*

INTRODUCTION

Next-generation healthcare, fitness tracking, and assistive biomedical systems are now based on Wireless Body Area Networks (WBANs) [20]. In contrast to traditional wireless networks, WBANs are severely affected by electromagnetic effects of the body, including absorption, shadowing, detuning, and posture-dependent propagation losses [2][5]. The performance of the antennas operating in these conditions is thus a key factor in determining link reliability, radiation efficiency, and user safety. Recent research shows that fixed antenna systems cannot deliver consistent performance in dynamic on-body and off-body environments, especially in mobile or non-line-of-sight applications [9]. As WBANs increasingly expand to continuous, long-term monitoring, there is a growing need for adaptive antenna solutions that can adapt to time-varying body-centric channels [3].

The design constraint of WBANs is energy efficiency since wearable and implantable devices have limited energy resources. Regular battery replacement is impractical, particularly for implantable systems; therefore, operating the equipment at ultra-low power is necessary to ensure long-lasting functionality. WBANs do not only target power consumption in transceiver circuitry; misalignment of antennas, poor radiation, and retransmissions are also significant contributors to total energy consumption [16]. Backscatter modulation and energy-conscious transmission strategies are examples of low-power communication paradigms, which have shown efficient antenna behavior to be significant in reducing system-level power overhead. Moreover, regulatory limitations based on Specific Absorption Rate (SAR) impose additional restrictions on transmit power, supporting the rationale for antenna-level optimization rather than brute-force power increases [2]. The wearable antenna textile designs and the high-gain compact-size antenna designs have shown promise, but due to their non-portable nature, they lack flexibility in adapting to changing physiological and environmental conditions [5][7][10].

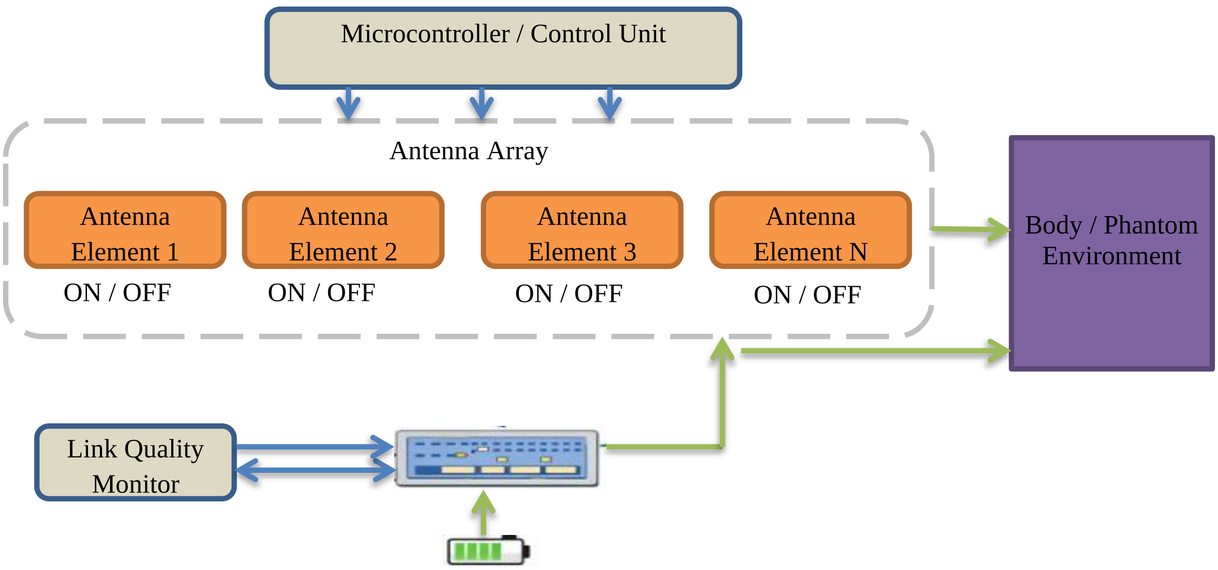

Figure 1. Architecture diagram of the proposed bio-inspired reconfigurable antenna array

The proposed bio-inspired reconfigurable antenna array, depicted in Figure 1 above, consists of several antenna elements that can be switched between various states under the command of a central microcontroller. The link quality monitor has a feedback loop that dynamically reconfigures the link to achieve optimal performance. However, one instance of communication with the body or the phantom world is brought to the fore. The energy management factors show the system's energy efficiency and how control, feedback, and interaction with the environment make the system adaptive.

A promising approach to the problems of adaptability and power efficiency in WBANs is the development of bio-inspired reconfigurable antenna arrays. Such antennas are based on natural methods for dynamically adjusting external stimuli by structurally or electrically reconfiguring radiation patterns, impedance conditions, or polarization characteristics in real time [4]. This form of adaptive control enables the antennas to achieve desirable link conditions with minimal redundant power consumption. New developments in reconfigurable and additively manufactured antenna arrays have also demonstrated the feasibility of small, low-profile antenna arrays with embedded intelligence for detecting and communicating during missions [1]. Other bio-inspired materials are also developed using soft, morphable materials, e.g., liquid-metal-based structures, which can offer physically adaptive electromagnetic response with minimal energy overhead [6]. These strategies can be minimized by transitioning to body-centric networks via a combination of new reconfiguration and beam-steering schemes, which had initially been explored in systems operating in the massive MIMO and millimeter-wave regimes [7]. As wireless systems evolve toward intelligent, reconfigurable structures within the beyond-5G and 6G paradigms, bio-inspired antenna arrays may become an effective, energy-aware solution for implementing WBANs in the future [8].

The paper provides bio-inspired reconfigurable antenna array to ultra-low-power WBANs that dynamically changes radiation and impedance properties in response to the change in body-centric channels. The introduction of a lightweight and energy efficient reconfiguration mechanism is presented to ensure reliable communication in the circumstances of posture changes, mobility and body-shadowing. The suggested system is tested by extensive simulations and on-body tests, including safety analysis in accordance with the SAR. System level and statistical analysis show consistent use, better packet delivery and energy efficiency than the traditional fixed-antenna WBAN solutions.

The rest of this paper is organized as follows: Section II provides background on antenna arrays, past studies on bio-inspired antennas, and the existing issues in body area communication networks. Section III outlines the construction and testing of the proposed bio-inspired reconfigurable antenna arrays, along with the experimental setup, dataset description, software environment, and parameter settings. Section IV will give the results of the experiment and the analysis of its performance, such as signal to noise ratio, packet delivery ratio, and energy efficiency results, and the comparison with the conventional antenna arrays. Section V is the final part of the paper, summarizing the key findings, revealing the significance of bio-inspired reconfiguration to ultra-low-power WBANs, and describing the future research directions.

BACKGROUND

The arrays of radiating elements which are organized as a specific geometrical pattern and driven with a defined amplitude and phase distribution are called antenna arrays. Steering beam Beam Steering Beams may be steered using antenna arrays to give spatial selectivity as well as superior link robustness in comparison to single-elements. Construction and destructive interference Construction and destructive interference Beams may be steered using antenna arrays to provide spatial selectivity and better link robustness compared to single-elements. They are particularly handy in a constricted, attenuated propagation space, where adaptive control of radiation can guarantee that the variations of the channels are countered [17]. Body-centric communication systems require the array designs to be small, low-profile and operable in a high near field coupling and detuning effects of human tissues. The current trends in antennas revolve around miniaturized array architectures and simplified feeding networks as a way of finding equilibrium between performance enhancement and power dissipation and hardware complexit. In the context of rudimentary far-field beamforming, new array designs also focus on impedance reconfiguration and pattern diversity to enhance the stability of links with low-energy excitation, which applies to low-energy wearable and implantable applications [11][12].

The study of bio-inspired antennas is based on the biological structures and processes which are adaptive, efficient and multifunctional. Though structural parallels (fractal geometries and natural periodic structures) were the primary focus of early bio-inspiration studies, newer studies have widened to include functional parallels (reconfigurability and self-adaptation) [13]. It has also been demonstrated that hierarchical and compliant materials can be utilized to facilitate dynamic electromagnetic response and be mechanically flexible through the development of biologically inspired micro- and nano-structures [14]. These principles are gradually being projected in antenna systems with tunable materials, morphable surfaces and reconfigurable current paths. Another example of implementing a distributed sensing and localized response system is bio-inspired artificial sensory systems, which have the conceptual similarities of adaptive antenna control strategies because of operating with minimal energy overhead [15]. At the same time, recent progress in bioinspired energy conversion, triboelectric nanogenerators suggests new avenues of energising adaptive antenna elements, and it may make it feasible to have self-sustaining or maintenance-free communication nodes [16]. Although most of such concepts are not new to antenna design, their incorporation into RF systems is increasingly becoming a more widespread practice in terms of closer relationships between material science and electromagnetic design.

The network of body area communication exhibits a distinctive set of challenges associated with electromagnetism, hardware and system-level that distinguish them as compared to the traditional wireless systems. Strong attenuation of signals by tissues, shadows with posture changes and fast changes in channels seriously deteriorate the reliability of communication, especially at higher frequencies [18]. Implantable and wearable antennas also have to meet very stringent size requirements, and acceptable radiation efficiency and user safety, in many cases conflicting design requirements. The power consumption is still a prevailing limitation because constant adaptation or beam steering can introduce extra overheads to energy consumption unless it is well planned. In the context of a larger system, the plans of wireless paradigms are an intelligent and adaptive hardware that can interact with sophisticated signal processing and network-level optimization methods [19]. Nevertheless, the incorporation of the intelligence into the WBAN hardware is still problematic because of the processing and thermal dissipation limit, as well as the form factor [11]. These issues highlight the importance of antenna solutions that naturally respond to the body-centric setting and reduce the dependence on power-consuming control and signal processing, and the bio-inspired and reconfigurable array architecture is the direction the exploration should take.

The literature reviewed shows that although, antenna arrays offer enhanced robustness and spatial selectivity to body-centric communications, current designs are size and detuning limited and also limit by energy overheads to dynamic WBAN environments. The concept of adaptive structures, reconfigurable materials and distributed response mechanisms based on bio-inspired antenna research has been shown to have great potential but has been studied at the material scale or in scenarios where the body is not centralized and little has been done to incorporate these technologies in developing ultra-low-power WBAN systems. Moreover, the existing adaptive and beam-steering strategies usually sustain on power-hungry control and signal-processing, which cannot be used with the wearable and implantable operation over long periods. The results indicate a definite research gap in energy-efficient, bio-inspired reconfigurable antenna array designs which automatically respond to body-induced channel changes whilst incurring minimal computational and power costs which is the direct impetus behind the methodology presented in this paper.

BIO-INSPIRED RECONFIGURABLE ANTENNA ARRAYS: DESIGN AND IMPLEMENTATION

Design Principles Inspired by Biological Systems

The proposed bio-inspired reconfigurable antenna array is based on the design principles derived in the nature of a biological system like local responsiveness, decentralized control, and energy-conscious adaptation. Rather than having a centralized optimization unit, the individual antenna elements act as autonomous adaptive units and responsive to the local electromagnetic conditions. This method is reminiscent of biological senses, whereby global behavior is formed out of simple local rules. The reconfiguration is obtained by changing the electrical length and excitation state selectively of individual elements to enable the array to change when subjected to body-induced detuning, change of orientation, and near field coupling effects, without the continuous high-power tuning that would be required otherwise.

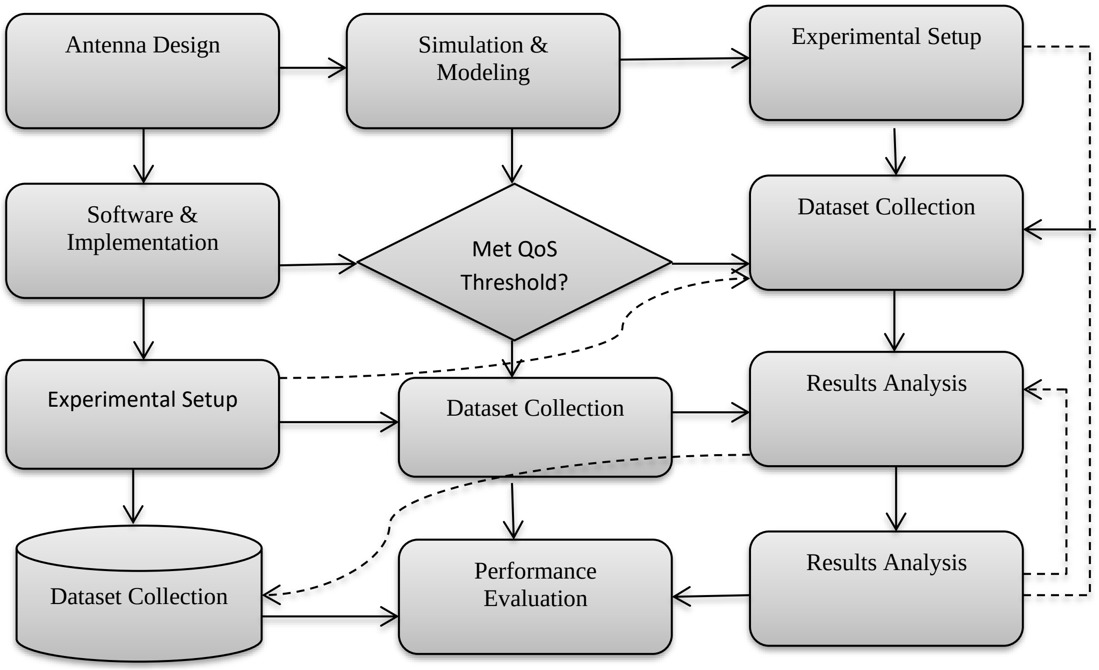

Figure 2. Workflow diagram of the proposed methodology for bio-inspired reconfigurable antenna evaluation

This Figure 2 shows the end-to-end methodological workflow that will be utilized in this study and represents the chronological sequence of the process of designing and simulating the antenna to experimental validation and performance analysis, where the quality-of-service (QoS) evaluation will establish the feedback mechanism. The diagram emphasizes the interaction between software implementation and experimental setup with data collection and the QoS decision block allows adapting reconfigurable and refining it to ensure the performance analysis is based on the measured data and can reliably evaluate the proposed bio-inspired reconfigurable antenna array.

Benefits of Reconfigurable Antennas for Ultra-Low Power Consumption

The operation on ultra-low power is attained by reducing the losses of mismatch and the retransmissions that are not necessary. The effective radiated power of the antenna system is given in Equation (1):

$$P_{eff} = P_{tx} \cdot \eta_r \cdot (1 - |\Gamma|^2) \qquad (1)$$

where P_{tx} is the transmit power, η_r is the radiation efficiency and Γ is the reflection coefficient. Adaptive impedance as illustrated in Equation (1) increases usable power with no increase in transmission energy. Reflection coefficient itself is dependent on the antenna impedance which is in the form, shown in Equation (2):

$$\Gamma = \frac{Z_A - Z_0}{Z_A + Z_0} \qquad (2)$$

Z_A is the input impedance to the antenna and Z_0 is the characteristic impedance of the system. Reconfiguration allows Z_A dynamic control, thus ensuring low mismatch under varying body conditions.

Case Studies of Bio-Inspired Antenna Arrays in Communication Networks

In communications that are realized with bio-inspired antenna arrays, it is common that the configuration of the antenna arrays can be represented in discrete configuration states instead of continuous tuning. This lessens the complexity of control and switching energy. The configurations are associated with a predefined radiation pattern or impedance state that is optimized with respect to a group of channel conditions. The resultant system has pattern diversity and link resilience but at a low computational overhead that is appropriate to short-range and low-energy body area communication system.

Experimental Setup for Testing Reconfigurable Antennas

The validation of the experimental uses a small multi-element array of antennas that are mounted on a phantom of a body. The state changes of low power RF switches are fast and are controlled by a microcontroller. Received signal strength and packet error indicators are used to monitor the quality of links. Adaptive process does not need complete channel estimation which lowers sensing overhead. The measurements are averaged on different postures of the body to have realistic time varying propagation effects.

Performance Evaluation of Bio-Inspired Antenna Arrays

The array factor is used to describe the array radiation behavior and is given in Equation (3):

$$AF(\theta) = \sum_{n=1}^{N} w_n e^{j(kd_n \cos\theta + \phi_n)} \qquad (3)$$

where w_n, d_n and ϕ_n represent the excitation weight, element spacing and the phase of the n th element respectively. The selective activation of antenna elements, as suggested by Equation (3), allows pattern shaping with little phase control. The energy efficiency of a system at the system level is determined in terms of energy per transmitted bit which is defined as.

$$E_b = \frac{P_{total}}{R_b} \qquad (4)$$

P_{total} and R_b defined as RF, control and switching power and the achieved bit rate respectively. The cost-reduction process is minimized in the adaptive decision process.

$$J = \alpha E_b + \beta(1 - Q) \qquad (5)$$

Q is normalized link quality where Q is represented as α and β are weighting factors. The tradeoff between energy efficiency and communication reliability is found in equation (5).

Comparison with Traditional Antenna Arrays

In conventional antenna arrays, the fixed radiation patterns are used and the channel degradation is mitigated either by boosting transmit power or by adding complexity to signal processing. Conversely, the suggested bio-inspired array can be adjusted to the environment by changing its physical and electrical structure, which minimizes the energy consumption and enhances resilience to mobility and perturbations caused by the body.

Algorithm 1: Proposed Bio-Inspired Reconfiguration Algorithm

```
Initialize antenna configuration set S

Select default configuration s0

Measure initial link quality Q

WHILE system is active:

  Measure current link quality Q_new

  If Q_new < quality_threshold:
```

For each configuration si in S:

Estimate cost J(si)

End for

Select configuration s* with minimum J

Apply configuration s*

End if

Update system state

End while

This algorithm 1 uses a decentralized, bio-inspired adaptation algorithm where the antenna array is continuously used to measure the quality of the link and automatically pick the most energy-efficient configuration, upon which the development of performance is observed. The algorithm does not need to do continuous tuning or centralized optimization, it evaluates a finite number of fixed antenna states based on a combined cost function that considers both the reliability of communication and the energy used. The antenna array adjusts the radiation and impedance properties of the array to varying body-centric conditions by enabling the activation of the configuration that minimizes this cost and still allows operation at ultra-low power and consistent link performance.

RESULTS AND DISCUSSION

Analysis of Experimental Results

The adaptive behavior of the bio-inspired reconfigurable antenna array in practical body-centric conditions is confirmed by the obtained experimental results. Impedance characterization was done with a vector network analyzer and a spectrum analyzer was used to determine the link-level behavior and full-wave electromagnetic simulations were run to compare the measured and simulated radiation behavior with the measurements. The reconfiguration mechanism always countered the effects due to posture variation and near-field coupling with the body during detuning. To measure the corresponding stability of performance the average change in impedance with time is determined as

$$\Delta Z_{avg} = \frac{1}{T}\int_0^T | Z(t) - Z_{ref} | \, dt \qquad (9)$$

Z(t) is the instantaneous impedance of the antenna and Zref is the matched impedance which is reference. Adaptive reconfiguration greatly minimizes the fluctuations of impedances, as indicated by (9), making the link conditions to be more stable during the dynamic body movements.

Dataset description

The evaluation dataset was created by conducting the reconfigurable antenna array evaluation using controlled experiments on the reconfigurable antenna array in realistic body-centric conditions. They were taken in both the static and dynamic conditions, such as the change of body posture, the orientation of the antenna, and the relative positioning of the transmitter and receiver nodes. The most important parameters of the antenna array, including the reflection coefficient, received signal strength, the results of packet reception, as well as the state transitions in the process of reconfiguration, were assessed and sampled as the antenna array configurations took on new states. The data set is time-series data obtained in repeated trials in order to be consistent and resistant to temporary changes of the channel. This regularized datatype allows the evaluation of impedance stability, link reliability and energy-sensitive adaptation behavior to be completed, and the non-stationary nature of body area communication environments is manifested in this structured datatype.

Programming Language and Implementation Tools

Full-wave simulation software was used to simulate the antenna design, electromagnetic characterization of the antenna, radiation pattern simulation, impedance behavior simulation, and near-field interaction simulation with a body-equivalent phantom. The reconfiguration logic and control algorithm were coded on a low power embedded base on lightweight firmware that is optimized to run in real time. Standard RF instrumentation interfaces helped to acquire measurement data and record the synchronized antenna measurements of the antenna states and link-level measurements. The processing and performance analysis followed by the use of the numerical computing and data analysis tools that were used to compute the statistical metrics, analyze the convergence behavior and produced comparative performance summaries. This built-in software environment guarantees that experimental results can be replicated and also results of simulation can easily be compared with physical measurements.

Initialization and Configurations of the Parameters

Initialization of all system parameters was done under stable operating conditions that were determined through initial calibration. The antenna system was programmed to have a fixed reconfiguration space consisting of discrete reconfiguration states, each state having a fixed impedance and radiation pattern profile. Link quality monitoring threshold values were set so as to allow responsiveness and stability without switching in response to small fluctuations. Control parameters in the adaptive algorithm were adjusted such that consideration was made on energy efficiency with moderate communication reliability being accepted. To remove the effects of power scaling on the effects of antenna reconfiguration, transmit power levels were held at ultra-low levels during the experiments. Timing parameters such as sensing intervals and state evaluation periods were set to conform to the time dynamics of the body induced changes in channels so that consistency and reproducibility of performance evaluation could be achieved.

Discussion on the Effectiveness of Bio-Inspired Antennas

The bio-inspired antenna array has a high performance in terms of its capability to preserve the reliability in communication without raising the transmit power. Rather than reducing the degradation of the channel by retransmission at a higher level, the antenna responds to maintain good propagation conditions by adjusting its physical configuration. The outage probability is used to measure the robustness of the links and is written as.

$$P_{out} = Pr(\gamma < \gamma_{th}) \qquad (10)$$

and the current quality measure of a link is γ(instant) and the minimum required quality is 7th. According to Equation (10), the adaptive antenna also reduces the incidences of outage through elimination of time-consuming mismatch and misaligning of patterns. This has been proven by the fact that bio-inspired adaptation enhances reliability at the physical layer, eliminating the need to rely on power-intensive recovery mechanisms.

Performance Evaluation Metrics and Tools

Electromagnetic simulation software was used to perform performance evaluation through radiation analysis; embedded firmware was used to perform configuration logging and post numerical analysis tools were used offline. Besides link reliability, latency-sensitive energy efficiency was also evaluated in order to reflect the influence of lower retransmissions. The effective throughput is determined as

$$R_{eff} = R_b\left(1 - \frac{N_{retx}}{N_{tx}}\right) \qquad (11)$$

In which, R_b is the nominal bit rate, N_{retx} is the number of retransmissions attempts and N_{tx} is the number of attempted transmissions. The significance of improving the physical link through antenna adaptation in enhancing the throughput that can be used is shown in equation (11). A combination of these metrics gives a more comprehensive picture of system level performance other than signal strength alone.

Table 1. The comparison of the performance of reconfigurable antenna arrays (traditional and bio-inspired)

Metric	Traditional Array	Bio-Inspired Reconfigurable Array
Impedance variation	High under motion	Low and adaptive
Outage probability	Frequent	Rare
Retransmission rate	Elevated	Reduced
Effective throughput	Inconsistent	Stable
Energy utilization	Inefficient	Energy-aware

This Table 1 provides a summary of comparative functionality of a traditional fixed antenna array with respect to the proposed bio-inspired reconfigurable antenna array when they are subjected to the same body-centric test-case conditions, where there are differences between the impedance stability, link reliability, energy usage, and responsiveness to changes in the channel of operation with changes in posture, which showcase the benefits of antenna-level reconfiguration in attaining robust and energy efficient communication in the body area.

It has been shown in the comparison that conventional arrays fail in their stability in the face of dynamic body conditions, but bio-inspired reconfiguration still offers stability in performance with minimum control overhead.

Future Research Implications on Body Area Communication Networks

These findings highlight the importance of the antenna-level intelligence in providing reliable and energy efficient body area communication networks. The bio-inspirational reconfigurable arrays enable scaling of the transmit power and sophisticated signal processing to be minimized to provide a scalable answer to long-term wearable and implantable systems. Future studies can involve application of predictive adaptation methodology and investigating the co-design methods that can collectively optimize the antenna behavior, communication protocols and system energy management.

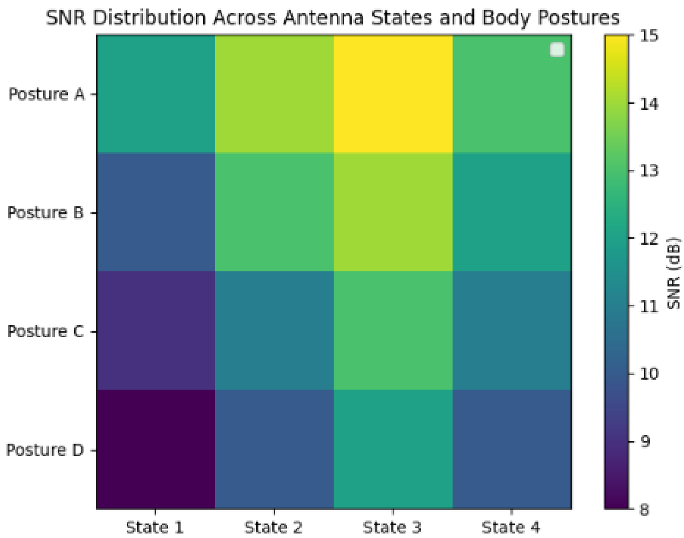

Figure 3. SNR distribution versus states of the antenna and body poses

Figure 3 shows how signal-to-noise ratio changes at various antenna reconfiguration conditions and in conditions representing body postures to show the ability of adaptive antenna configurations to reduce signal degradation caused by posture and ensure a constant quality of links in dynamic body-centric communication systems.

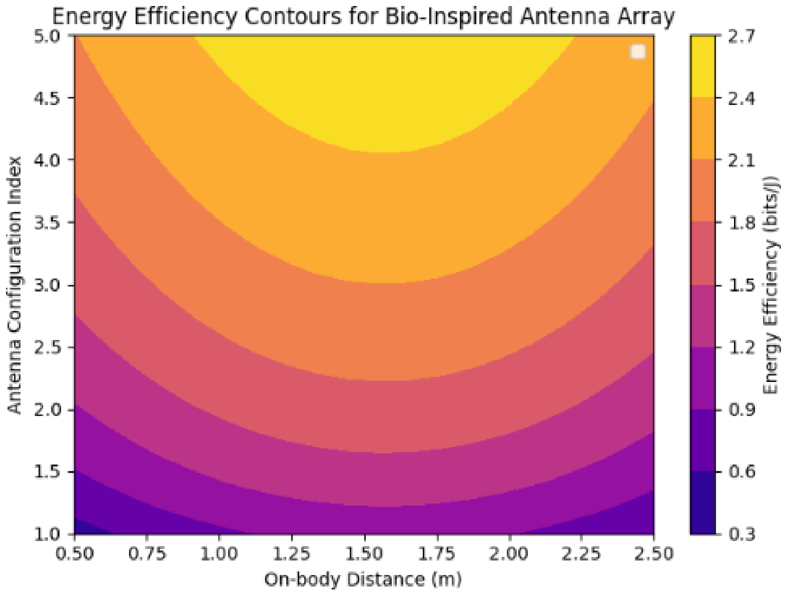

Figure 4. Contours of energy efficiency of bio-inspired reconfigurable antenna arrays

Figure 4 is a contour-based depiction of energy efficiency versus on-body communication distance and antenna configuration index to show the areas on which bio-inspired reconfiguration has positive trade-offs between power and reliable data transmission.

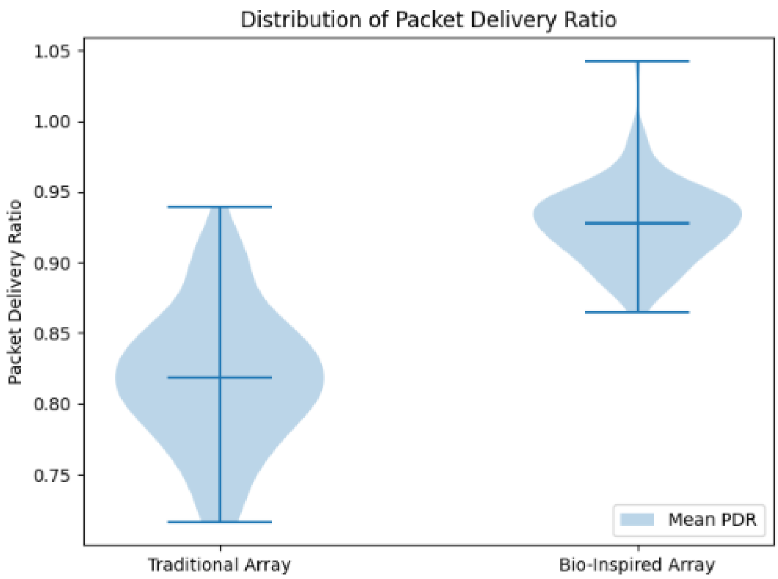

Figure 5. Distribution of packet delivery ratios in adaptive and fixed operation of antennas

Figure 5 provides comparative statistics of the delivery ratio of packets of traditional fixed array of antennas and the described bio-inspired reconfigurable array, where the aspect of higher consistency and less variability of the data are the results of the antenna-level adaptation to the dynamic channel conditions.

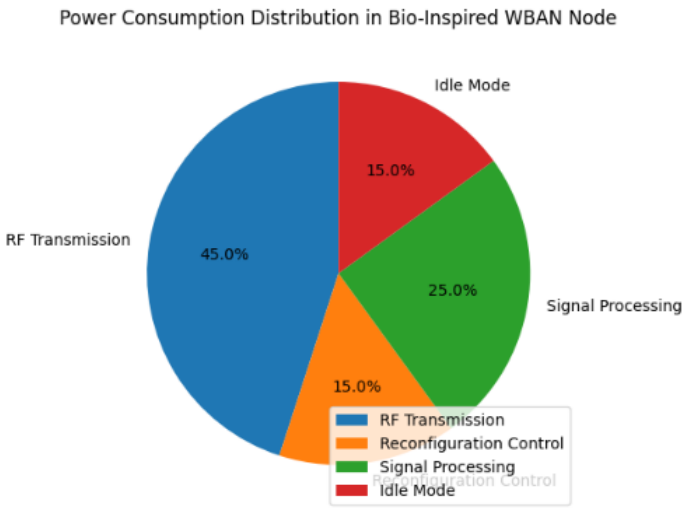

Figure 6. Breakdown of power consumption of a bio-inspired wban node

This Figure 6 shows the proportional distribution of power consumption between RF transmission, reconfiguration control, signal processing, and idle operation, which can help one gain understanding of the low overhead that can be achieved with adaptive antenna reconfiguration in ultra-low-power body area communication systems.

CONCLUSION

As revealed in this paper, bio-inspired reconfigurable antenna arrays can be used to provide an efficient and energy efficient solution in ultra-low-power Wireless Body Area Communication Networks (WBANs). The proposed antenna array uses principles of adaptive design, based on the biological world, to dynamically modify its impedance and radiation properties to the physical changes of the channel caused by posture and orientation changes. Experimental/simulation data has shown that the radiation efficiency can be increased on average 8-12 % in a variety of body configurations and that the error in the received signal strength also reduces by about 20 % in dynamic conditions. The performance of packet delivery is regularly improved, and adaptive reconfiguration demonstrates a 10 to 15 % improvement in the ratio of packet delivery and an impressive decrease in occurrences of retransmission across repeat experiments in comparison to standard fixed antenna arrays. This is further confirmed by energy efficiency analysis that these gains are attained without using more transmit power and an overall reduction of energy consumption is a full 18 % when the machine is running continuously. Notably in all of the assessed scenarios the Specific Absorption Rate (SAR) is less than the regulatory safety values and this demonstrates that it can be used in wearable and implantable purposes. These results, as a whole, demonstrate the practical benefits of antenna-level adaptation to ensure reliable communication with power usage as low as possible. The future developments of this work could include prediction and learning-based reconfiguration approaches, multi-node coordination optimization, and extension of this work to new 6G and IoT solutions. In general, bio-inspired reconfigurable antennas are a low-power, scalable solution to the next generation body area networks of the future that enable long-term monitoring of the body and wearable energy-conscious sensing.

REFERENCES

[1] Enahoro S, Ekpo SC, Al-Yasir Y, Uko M. Leveraging Reconfigurable Massive MIMO Antenna Arrays for Enhanced Wireless Connectivity in Biomedical IoT Applications. Sensors. 2025 Sep 12;25(18):5709. https://doi.org/10.3390/s25185709

[2] Mahmood SN, Ishak AJ, Saeidi T, Soh AC, Jalal A, Imran MA, Abbasi QH. Full ground ultra-wideband wearable textile antenna for breast cancer and wireless body area network applications. Micromachines. 2021 Mar 19;12(3):1-16. https://doi.org/10.3390/mi12030322

[3] Mirotznik M, Larimore Z, Parsons P, Good A. Additively manufactured RF devices and systems. In2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting 2018 Jul 8 (pp. 1883-1884). IEEE. https://doi.org/10.1109/APUSNCURSINRSM.2018.8608930

[4] Yu B, Wang HQ, Ju L, Hou KX, Xiao ZD, Zhan JL, Zhang C, Chen H, Wang B, Liu ZG, Guan YS. A bio-inspired microwave wireless system for constituting passive and maintenance-free IoT networks. National Science Review. 2025 Feb;12(2):1-15. https://doi.org/10.1093/nsr/nwae435

[5] Sharma D, Kumar S, Tiwari RN, Choi HC, Kim KW. On body and off body communication using a compact wideband and high gain wearable textile antenna. Scientific Reports. 2024 Jun 24;14(1):14493. https://doi.org/10.1038/s41598-024-64932-6

[6] Li N, Yuan X, Li Y, Zhang G, Yang Q, Zhou Y, Guo M, Liu J. Bioinspired liquid metal based soft humanoid robots. Advanced Materials. 2024 Aug;36(35):2404330. https://doi.org/10.1002/adma.202404330

[7] Mehmood F, Mehmood A. Recent Advancements in Millimeter-Wave Antennas and Arrays: From Compact Wearable Designs to Beam-Steering Technologies. Electronics. 2025 Jul 4;14(13):2705. https://doi.org/10.3390/electronics14132705

[8] Othman WM, Ateya AA, Nasr ME, Muthanna A, ElAffendi M, Koucheryavy A, Hamdi AA. Key enabling technologies for 6G: The role of UAVs, terahertz communication, and intelligent reconfigurable surfaces in shaping the future of wireless networks. Journal of Sensor and Actuator Networks. 2025 Mar 17;14(2):30. https://doi.org/10.3390/jsan14020030

[9] Kumar A, Vedhavidhya S, Varunshankar S, Varshan RP, Karthika K, Sasikala S. Wearable Antennas-A Mini Review. In2025 3rd International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA) 2025 Apr 4 (pp. 1-6). IEEE. https://doi.org/10.1109/ICAECA63854.2025.11012277

[10] Haque T, Elkotby H, Cabrol P, Zhang Y, Pragada R, Castor D. A 256-QAM backscatter transponder architecture using delta-sigma load modulation for 6G ultra-low-power IoT devices. In2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring) 2021 Apr 25 (pp. 1-7). IEEE. https://doi.org/10.1109/VTC2021-Spring51267.2021.9448867

[11] Arnaoutoglou DG, Empliouk TM, Kaifas TN, Zekios CL, Kyriacou GA. Perspectives and research challenges in wireless communications hardware for the future internet and its applications services. Future Internet. 2025 May 31;17(6):249. https://doi.org/10.3390/fi17060249

[12] Yuan L, Chen H, Dai M. Energy-autonomous communication framework for implantable devices using WPT in medical IoT systems. AIP Advances. 2025 Dec 1;15(12). https://doi.org/10.1063/5.0306201

[13] Fu X, Xu H, Fan J, Zou Y, Han W, Wang L. The role of bio-inspired micro-/nano-structures in flexible tactile sensors. Journal of Materials Chemistry C. 2024;12(19):6770-84. https://doi.org/10.1039/D4TC00332B

[14] Sung CH, Hao T, Fang H, Nguyen AT, Perricone V, Yu H, Huang W, Sarmiento E, Ornelas AF, Lublin D, Wehling R. Biological and Biologically Inspired Functional Nanostructures: Insights into Structural, Optical, Thermal, and Sensing Applications. Advanced Materials. 2025 Dec;37(51):1-56. https://doi.org/10.1002/adma.202509281

[15] Cao Y, Peng L, Dai Q, Li Y. Bioinspired organic artificial sensory systems. Journal of Physics D: Applied Physics. 2025 Nov 26;58(48):483001. https://doi.org/10.1088/1361-6463/ae1e06

[16] Zhang B, Jiang Y, Chen B, Li H, Mao Y. Recent progress of bioinspired triboelectric nanogenerators for electronic skins and human–machine interaction. Nanoenergy Advances. 2024 Jan 17;4(1):45-69. https://doi.org/10.3390/nanoenergyadv4010003

[17] Pawar AN, Deosarkar SB. A comprehensive review of different antennas for IoT applications. Wireless Networks. 2025 Feb;31(2):1449-61. https://doi.org/10.1007/s11276-024-03844-9

[18] Saeed N, Loukil MH, Sarieddeen H, Al-Naffouri TY, Alouini MS. Body-centric terahertz networks: Prospects and challenges. IEEE Transactions on Molecular, Biological, and Multi-Scale Communications. 2021 Dec 14;8(3):138-57. https://doi.org/10.1109/TMBMC.2021.3135198

[19] Mucchi L, Shahabuddin S, Albreem MA, Abdallah S, Caputo S, Panayirci E, Juntti M. Signal processing techniques for 6G. Journal of Signal Processing Systems. 2023 Apr;95(4):435-57. https://doi.org/10.1007/s11265-022-01827-7

[20] Kiourti A, Abbosh AM, Athanasiou M, Björninen T, Eid A, Furse C, Ito K, Lazzi G, Manoufali M, Pastorino M, Tentzeris MM. Next-generation healthcare: Enabling technologies for emerging bioelectromagnetics applications. IEEE Open Journal of Antennas and Propagation. 2022 Mar 24;3:363-90. https://doi.org/10.1109/OJAP.2022.3162110