

## Development of data power control algorithms for downlink transmission in cooperative Wireless Body Area Networks

Do Thanh Quan<sup>1</sup>, Bui Tien Anh<sup>2</sup>, Do Khanh Vinh<sup>3</sup>, Bo Quoc Bao<sup>4\*</sup>

<sup>1</sup>Faculty of Technical Command and Staff, Le Quy Don Technical University;

<sup>2</sup>Faculty of Radio-Electronic Engineering, Le Quy Don Technical University;

<sup>3</sup>Military Institute of Drug, Medical Equipment Quality Control and Research;

<sup>4</sup>Faculty of Electronics, Hanoi University of Industry.

\*Corresponding author: [baobq@hau.edu.vn](mailto:baobq@hau.edu.vn)

Received 03 Aug. 2023; Revised 19 Sep. 2023; Accepted 10 Nov. 2023; Published 25 Nov. 2023.

DOI: <https://doi.org/10.54939/1859-1043.j.mst.91.2023.11-19>

### ABSTRACT

*Wireless Body Area Networks (WBANs) are gaining significant attention for their versatile applications in various fields, including military, healthcare, emergency response, sports, and entertainment. Particularly in remote health monitoring and care, WBANs show great promise. In this article, the authors introduce the "Cooperative WBANs" model, wherein sensors communicate directly with Access Points (APs) without a coordinator. They also present a power control algorithm for downlink data transmission from APs to sensors. Simulation results demonstrate that controlling data transmission power significantly enhances sensor throughput, leading to improved system quality.*

**Keywords:** Wireless Body Area Networks; Downlink data transmission; Data power control; Channel estimation.

### 1. INTRODUCTION

Recently, wireless communication systems have surged, driven by the Internet of Things (IoT), which generates vast and diverse data. Fast connectivity and efficient processing with 6G networks are crucial. According to the authors in the research study [1], 6G mobile networks are expected to make significant advancements, and researchers have investigated applications such as super-intelligent societies, artificial intelligence, and integrated information and energy transmission. A specific focus is on body-worn sensors connected to APs using the Cell-free Massive Multiple-Input Multiple-Output (CFMIMO) system, ensuring multi-user support without the need for cell division. The analysis in [2] has shown that the CFMIMO system benefits from an improved channel gain and provides equal service for all users.

Many papers have explored the advantages of WBANs for remote health monitoring [3-5]. Investigations in [6] have shown that the use of sensors directly connected to APs improves connectivity flexibility and reliability. WBANs integrated with cell-free systems hold promise as a key application in the 6G mobile network. Research conducted in [7-10] involves an extensive examination of WBAN models, diagrams, and MAC layer controls, with a primary focus on system design rather than practical scenarios. For instance, the writers in [10] proposed a clustered WBAN model to enhance throughput, the contributors in [11] optimized the radio frequency spectrum to improve remote healthcare services, and the experts in [12] enhanced data transmission power in WBANs. The following survey models emphasize sensor data transmission to enhance cell-free models. Scientists in [13] have noted that cold storage technology enhances device durability, enabling the detection of critical points for cell-free biosensors. Additionally, researchers in [14] demonstrated the potential of cell-free

technology in identifying water source pollutants. Although CFMIMO and wireless sensor networks have advantages, their combination in wireless communication is limited. Authors in [15] proposed a method using a multi-node sensor network to transmit patient information to healthcare workers. Furthermore, the study in [16] demonstrated the application of ultra-wideband technology in high-speed data transmission within a narrow range in WBANs. However, these methods rely on wireless signals and involve lengthy computation times, making them unsuitable for patient treatment models in hospital rooms.

The research aims to develop a power control algorithm for AP-to-sensor data transmission, enhancing throughput and addressing the cooperative WBANs system quality. In addition, we contrast two WBAN approaches: cooperative and distributed. In the distributed system paradigm, each sensor is supported by a solitary AP with the most substantial mean usable signal strength. Once a sensor has established a successful connection with an AP, that AP becomes inaccessible to other sensors [17]. The paper is organized as follows: Section 2 introduces the cooperative WBANs system model and path loss model, serving as the basis for channel estimation, signal processing, and power control algorithm in Section 3. Section 4 covers the parameter setup and simulation results evaluation. Finally, Section 5 presents the paper's conclusion.

Mathematical notations used in the paper: Boldface type denotes a column vector,  $()^*$  denotes the transpose matrix,  $()^H$  denotes the conjugate transpose matrix,  $\|\cdot\|$  is Euclidean norm and  $E\{\cdot\}$  is expectation operators,  $z \sim CN(0, \sigma^2)$  denotes a circularly symmetric complex Gaussian random variable (RV) with zero mean and variance  $\sigma^2$ ,  $z \sim N(0, \sigma^2)$  denotes a realvalued Gaussian RV.

## 2. COOPERATIVE WBANS SYSTEM MODEL

The proposed cooperative WBANs model in this paper introduces a new approach where sensors directly communicate with APs, without a coordinator (figure 1). The model comprises  $M$  APs and  $K$  sensors, each equipped with a single antenna, placed on patients in a hospital treatment room. APs connect to the CPU via a backhaul link. Assuming the APs and sensors utilize the IEEE 802.15.6 standard for Medium Access Control (MAC), which enables multiple antennas to create focused beams for signal transmission and reception without interference. As devices often have multiple antennas to increase channel gain, the research on multi-antenna cases can be easily implemented based on the results presented in this paper. The cooperative WBANs model offers several advantages over traditional WBAN models: Firstly, enhanced flexibility and system reliability with multiple APs available for sensor connections. Secondly, an increased probability of Line of Sight connections, reducing Non Line of Sight scenarios. Finally, improved patient comfort during treatment by eliminating the need for a coordinator, which can be large and cause discomfort. However, this WBANs model has a limitation: We make the assumption that all APs are linked through an ideal backhaul, providing flawless and limitless data transmission to the CPU. Nevertheless, in real-world scenarios, the backhaul is likely to encounter substantial practical limitations.

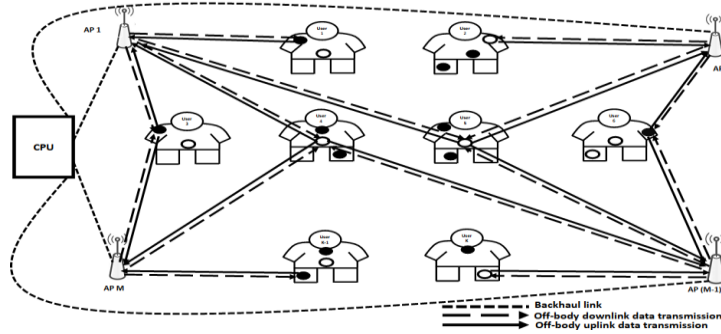


Figure 1. Cooperative WBANs system model.

The vector representing the transmission channel between the  $m^{th}$  AP and the  $k^{th}$  sensor [18] is denoted as  $v_{mk}$  and is calculated according to:

$$v_{mk} = p_{mk}^{1/2} q_{mk} \tag{1}$$

where,  $q_{mk}$  represents the small-scale fading. We assume that  $\{q_{mk}\}, m = 1, \dots, M, k = 1, \dots, K$  are independent and identically distributed RV. In practice, the sensors and APs are distributed in a small and confined area (such as a hospital treatment room), so the small-scale fading can be considered to have little effect on the transmission channel vector. Therefore, we only investigate the influence of the  $p_{mk}$  on the transmission channel vector  $v_{mk}$ .

Large-scale fading  $p_{mk}$  in (1), include two components are path loss and shadow fading, which are calculated using the following formulas:

$$p_{mk} = 10^{\frac{PL_{mk}}{10}} \tag{2}$$

where,  $PL_{mk}$  is the path loss component, which is calculated using the Floating-Intercept (FI) model [19, table 3], as follows:

$$PL^{FI}(d)[dB] = \alpha + 10\beta \log_{10}(d) + X_{\sigma}^{FI} \tag{3}$$

where,  $\alpha$  represents the floating intercept in dB,  $\beta$  indicates the line slope and  $X_{\sigma}^{FI}$  symbolizes the large-scale signal variabilities received against the distance in the direct path.

### 3. SIGNAL PROCESSING TECHNIQUES

#### 3.1. Channel Estimation

Let symbol  $\delta^c$  denotes the duration of the coherence interval, measured in samples. This value is calculated by multiplying the coherence time with the coherence bandwidth. Additionally, the symbol  $\delta^\alpha$  represents the duration of uplink training per coherence interval, also measured in samples. The following conditions are necessary  $\delta^\alpha \leq \delta^c$ . In the training stage, each of  $K$  sensors must transmit pilot sequences that are of length  $\delta^\alpha$  samples to the APs simultaneously. Let  $\sqrt{\delta^\alpha} \varphi_k \in \mathbb{C}^{\delta^\alpha \times 1}$  denote the pilot sequence used by the  $k^{th}$  sensor where  $\|\varphi_k\|^2 = 1$ . The received pilot vector at the  $m^{th}$  AP,

which has dimensions  $\delta^\alpha \times 1$ , can be expressed as follows:

$$\mathbf{y}_{p,m} = \sqrt{\delta^\alpha \rho_p} \sum_{k=1}^K v_{mk} \boldsymbol{\varphi}_k + \mathbf{w}_{p,m} \quad (4)$$

where,  $\rho_p$  represents the SNR and  $\mathbf{w}_{p,m}$  denotes a vector of additive noise at the  $m^{\text{th}}$  AP.

Let  $\check{y}_{p,mk}$  denote the projection of  $\mathbf{y}_{p,m}$  onto the conjugate transpose of  $\boldsymbol{\varphi}_k$ ,  $\boldsymbol{\varphi}_k^H$ :

$$\check{y}_{p,mk} = \boldsymbol{\varphi}_k^H \mathbf{y}_{p,m} = \sqrt{\delta^\alpha \rho_p} v_{mk} + \sqrt{\delta^\alpha \rho_p} \sum_{k' \neq k} v_{mk'} \boldsymbol{\varphi}_k^H \boldsymbol{\varphi}_{k'} + \boldsymbol{\varphi}_k^H \mathbf{w}_{p,m} \quad (5)$$

Estimations derived from  $\check{y}_{p,mk}$  are the best possible under these conditions. The minimum mean square error (MMSE) estimation for the variable  $v_{m,k}$ , given  $\check{y}_{p,mk}$ , is:

$$\hat{v}_{mk} = \frac{\mathbb{E}\{\check{y}_{p,mk}^* v_{mk}\}}{\mathbb{E}\{|\check{y}_{p,mk}|^2\}} \check{y}_{p,mk} = b_{mk} \check{y}_{p,mk}, \quad (6)$$

where,

$$b_{mk} \triangleq \frac{\sqrt{\delta^\alpha \rho_p} p_{mk}}{\delta^\alpha \rho_p \sum_{k'=1}^K p_{mk'} |\boldsymbol{\varphi}_k^H \boldsymbol{\varphi}_{k'}|^2 + 1}. \quad (7)$$

### 3.2. Downlink data transmission

The APs consider the channel estimates to be accurate and employ conjugate beamforming technique to send signals to the  $K$  sensors. The signal transmitted from the  $m^{\text{th}}$  AP can be expressed as:

$$x_m = \sqrt{\rho_d} \sum_{k=1}^K \lambda_{mk}^{1/2} \hat{v}_{mk}^* q_k \quad (8)$$

In the equation above,  $q_k$  is the symbol intended for the  $k^{\text{th}}$  sensor, and it is normalized so that its expected value of squared magnitude,  $\mathbb{E}\{|q_k|^2\} = 1$ . The power control coefficients  $\lambda_{mk}$ , where,  $m$  ranges from 1 to  $M$  and  $k$  ranges from 1 to  $K$ , are chosen to satisfy the power constraint at each AP, which can be expressed as follows:

$$\mathbb{E}\{|x_m|^2\} \leq \rho_d \quad (9)$$

Given the channel model in equation (1), the power constraint (9) can be restated as follows:

$$\sum_{k=1}^K \lambda_{mk} \gamma_{mk} \leq 1, \quad \text{for all } m \quad (10)$$

where,

$$\gamma_{mk} \triangleq \mathbb{E}\{|\hat{v}_{mk}|^2\} = \sqrt{\delta^\alpha \rho_p} p_{mk} b_{mk} \quad (11)$$

The signal received by the  $k^{th}$  sensor can be expressed as:

$$r_{d,k} = \sum_{m=1}^M v_{mk} x_m + \omega_{d,k} = \sqrt{\rho_d} \sum_{m=1}^M \sum_{k'=1}^K \lambda_{mk'}^{1/2} v_{mk} \hat{v}_{mk'}^* q_{k'} + \omega_{d,k} \quad (12)$$

Using the techniques in [17, part III, section B, subsection 1], we can calculate the attainable rate of the  $k^{th}$  sensor for cooperative WBANs operation as follows:

$$R_{d,k} = \log_2 \left( 1 + \frac{\rho_d \left( \sum_{m=1}^M \lambda_{mk}^{1/2} \gamma_{mk} \right)^2}{\rho_d \sum_{k' \neq k}^K \left( \sum_{m=1}^M \lambda_{mk'}^{1/2} \gamma_{mk'} \frac{P_{mk'}}{P_{mk'}} \right)^2 \left| \boldsymbol{\varphi}_k^H \boldsymbol{\varphi}_k \right|^2 + \rho_d \sum_{k'=1}^K \sum_{m=1}^M \lambda_{mk'} \gamma_{mk'} P_{mk'} + 1} \right). \quad (13)$$

### 3.3. Data power control

The implementation of data power control allows for a consistently high level of service quality for all sensors in a cooperative WBAN, regardless of their placement. The main strategy of the power control approach is to pursue maximum-minimum (egalitarian) fairness, which seeks to improve the lowest signal-to-interference-plus-noise ratio (SINR) among all sensors to its highest potential. This guarantees that all sensors receive the same level of SINR. This can be proven through contradiction, by assuming that a terminal has a higher SINR than the max-min SINR, and then reducing its power control coefficient to increase its SINR while ensuring that all other conditions are met. The aim of max-min fairness power control is to establish the same SINR objective for all sensors, and to identify the optimal SINR level that meets all requirements to ensure that all constraints are satisfied. By maximizing the minimum rate or SINR among all sensors within the network, max-min power control ensures that all sensors enjoy an equal and consistent quality of service. The power control process is executed by the CPU and is implemented over a large-scale fading time scale. The max-min power control algorithm focuses on maintaining a stable connection by adjusting the minimum required power for each node. However, the process of power adjustment can introduce a slight latency in data transmission or control, especially when a node needs to increase its power to meet higher transmission demands. This can potentially impact the real-time nature of certain healthcare or health monitoring applications within WBANs. Nevertheless, this latency is typically minimal and can be managed with appropriate algorithm configurations.

Our objective in the downlink is to determine appropriate values for the power control coefficients  $\lambda_{mk}$ ,  $m=1, \dots, M, k=1, \dots, K$  in order to maximize the minimum achievable rate among all sensors, while also ensuring that the power limit constraint (10) is satisfied. At the optimal solution, each sensor will be guaranteed an equal rate of data transfer. We can represent this mathematically using the following equation.

$$\begin{aligned} & \max_{\{\lambda_{mk}\}} && \min_{k=1, \dots, K} R_{d,k} \\ & \text{subject to} && \sum_{k=1}^K \lambda_{mk} \gamma_{mk} \leq 1, \quad m=1, \dots, M \\ & && \lambda_{mk} \geq 0, \quad k=1, \dots, K, \quad m=1, \dots, M. \end{aligned} \quad (14)$$

## 4. RESULTS AND DISCUSSIONS

### 4.1. Input data

In this research, all instances share the simulation setting in a medical facility room (8 m x 8 m x 3 m) with multiple patients wearing various sensors. APs are placed on the walls at a constant height of 3.0 meters, while sensor elevations range from 0.1 meters (ankle sensors) to 2.0 meters (head sensors). The simulation configuration specifications are detailed in table 1.

### 4.2. Methods, simulation tools

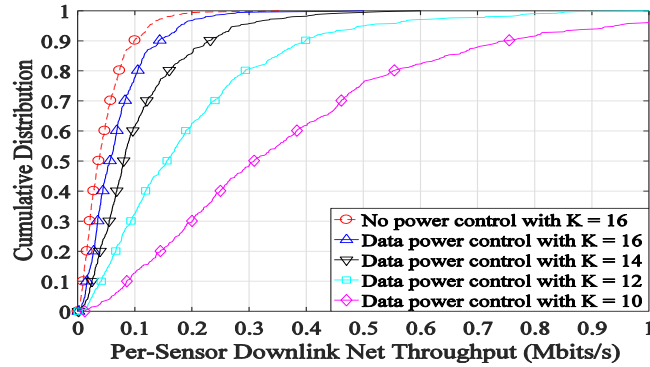
The process involves generating cumulative distributions of net throughput for individual sensors in downlink scenarios. Matlab software is used as the simulation tool. The simulation results were presented, illustrating the performance of our proposed model for WBANs. Specifically, the horizontal axis represents the throughput of the sensor nodes, while the vertical axis corresponds to the cumulative distribution function (CDF). The CDF serves as a statistical measure to analyze and evaluate the performance of the sensor nodes in terms of data transmission. By utilizing the CDF, we are able to assess the probability of successful data transmission within the sensor network. The simulation results displayed in the Matlab environment allow us to visualize and interpret the relationship between the throughput of the sensor nodes and the corresponding CDF. In the scenario with max-min power control, we follow these steps: Step 1 - Generate 200 random cases of AP and sensor locations; Step 2 - Calculate net throughputs for  $K$  sensors using max-min power control; Step 3 - Build cumulative distribution for each sensor. For scenarios without power control, we repeat the same procedure, except Step 2 does not include power control.

*Table 1. The settings of the simulation setup.*

Variable	Cost
Frequency ( $f$ ) and Bandwidth ( $B$ )	4.5 GHz, 10MHz
The number of AP ( $M$ ) and the number of sensor ( $K$ )	3,4,5,6; 10,12,14,16
$\alpha, \beta, \sigma$ of LoS environment	41.45, 1.32, 1.79
$\alpha, \beta, \sigma$ of NLoS environment	16.22, 4.83, 3.91
Height of the AP mounted on the wall ( $H_b$ )	3.0 m
The height of the sensor attached to the patient's body ( $H_m$ )	0.1 m – 2.0 m
The size of the treatment room (length $\times$ width $\times$ height)	8 m $\times$ 6 m $\times$ 3 m

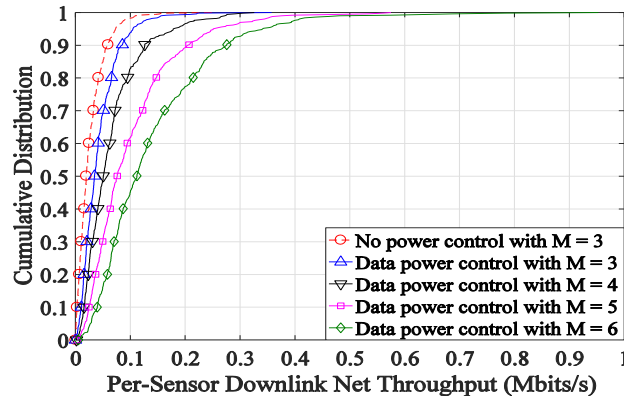
### 4.3. Simulation results and comments

The findings show that using data power control in the cooperative WBANs model leads to higher downlink average throughput compared to the system without data power control. Specifically, sensor throughput in the downlink scenario is extensively examined, as shown in figures 2, 3, and 4 depict. Figure 2 shows an increase in per-sensor average throughput with 4 APs ( $M$ ) and an increase in sensors ( $K$ ) from 10 to 16. Decreasing the number of sensors reduces interference, resulting in a higher achievable sensor rate according to equation (13), which enhances the efficiency of signal decoding.



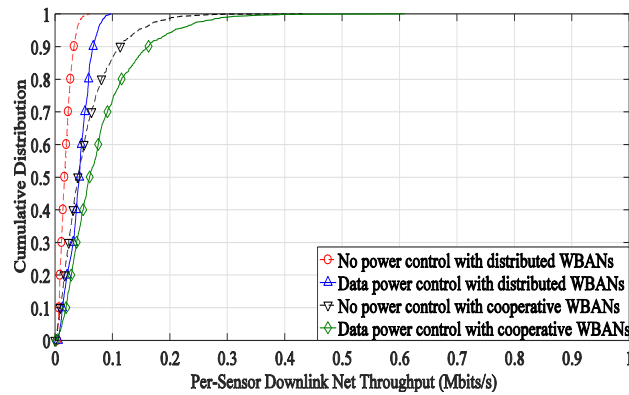
**Figure 2.** Per-sensor downlink net throughput with data power control in the case of  $M = 4$ .

Figure 3 shows simulations with  $K = 16$  and varying  $M$  from 3 to 6. Results demonstrate that increasing the number of APs leads to higher per-sensor throughput due to increased signal intensity, improving the achievable sensor rate.



**Figure 3.** Per-sensor downlink net throughput with data power control in the case of  $K = 16$ .

Figure 4 illustrates a comparison between the downlink net throughput per sensor in distributed and cooperative WBANs, with  $M = 4$  and  $K = 16$ . The results indicate that cooperative WBANs significantly outperform distributed WBANs in terms of net throughput.



**Figure 4.** Comparing the throughput per-sensor between cooperative and distributed WBANs in the case of  $M = 4$ ,  $K = 16$ .

## 5. CONCLUSIONS

The authors of this research paper propose a cooperative model for WBANs where all APs simultaneously serve all sensors using the same time and frequency resources. The APs are connected to the CPU and the public network through the backhaul link. To improve the downlink throughput, they apply an optimization method for the data power control factor after deriving a closed-form expression for the downlink throughput of each individual sensor. The results demonstrate that, across all considered scenarios, the system performance is significantly enhanced with data power control compared to the system without power control. Additionally, the impact of the number of sensors and APs on system quality is investigated. In future work, the authors plan to explore important aspects such as latency, priority, and power consumption, as well as develop and propose additional power control algorithms.

## REFERENCES

- [1]. H. Tataria, M. Shafi, A. F. Molisch, M. Dohler, H. Sjoland, and F. Tufvesson, “6g wireless systems: Vision, requirements, challenges, insights, and opportunities,” Proceedings of the IEEE, vol. 109, no. 7, pp. 1166–1199, (2021).
- [2]. G. Interdonato, “Cell-free massive mimo: Scalability, signal processing and power control,” Linkoping University Electronic Press, vol. 2090, (2020).
- [3]. U. Hariharan, K. Rajkumar, and A. Ponmalar, “WBAN for e-healthcare application: Systematic review, challenges, and counter measures,” in 2021 International Conference on Computer Communication and Informatics (ICCCI). IEEE, (2021).
- [4]. I. Pandey, H. S. Dutta, and J. S. Banerjee, “WBAN: A smart approach to next generation e-healthcare system,” in 2019 3rd International Conference on Computing Methodologies and Communication (ICCMC). IEEE, (2019).
- [5]. D. S. Bhatti, S. Saleem, A. Imran, Z. Iqbal, A. Alzahrani, H. Kim, and K.-I. Kim, “A survey on wireless wearable body area networks: A perspective of technology and economy,” Sensors, vol. 22, no. 20, p. 7722, (2022).
- [6]. B. T. Anh, D. T. Quan, and P. T. Hiep, “Developing the max-min power control algorithm for distributed wireless body area networks,” AEU - International Journal of Electronics and Communications, p. 154448, vol 158, (2023).
- [7]. P. T. Hiep and R. Kohno, “Control superframe for high throughput of cluster-based WBAN with CSMA/CA,” in 2014 IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC). IEEE, (2014).
- [8]. M. Ali, H. Mounqila, M. Younis, and A. Mehaoua, “Distributed scheme for interference mitigation of WBANs using predictable channel hopping,” in 2016 IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom). IEEE, (2016).
- [9]. B. Alte and A. Vidhate, “MAC protocol selection and performance analysis in wireless body area networks,” in 2022 IEEE 2nd Mysore Sub Section International Conference (MysuruCon). IEEE, (2022).
- [10]. P. T. Hiep, N. N. Thang, G. Sun, and N. H. Hoang, “Proposal of a hierarchical topology and spatial reuse superframe for enhancing throughput of a cluster-based WBAN,” ETRI Journal, vol. 41, no. 5, pp. 648–657, (2019).
- [11]. Y. Yang, D. Smith, J. Rajasegaran, and S. Seneviratne, “Power control for body area networks: Accurate channel prediction by lightweight deep learning,” IEEE Internet of Things Journal, vol. 8, no. 5, pp. 3567–3575, (2021).

- [12]. Z. Zhang, J. Huang, H. Wang, and H. Fang, "Power control and localization of wireless body area networks using semidefinite programming," in 2015 2nd International Symposium on Future Information and Communication Technologies for Ubiquitous HealthCare (UbiHealthTech). IEEE, (2015).
- [13]. T. Wang and Y. Lu, "Advances, challenges and future trends of cell-free transcription-translation biosensors," Biosensors, vol. 12, no. 5, p. 318, (2022).
- [14]. J. K. Jung, K. K. Alam, M. S. Verosloff, D. A. Capdevila, M. Desmau, P. R. Clauer, J. W. Lee, P. Q. Nguyen, P. A. Pasten, S. J. Matiassek, J.-F. Gaillard, D. P. Giedroc, J. J. Collins, and J. B. Lucks, "Cellfree biosensors for rapid detection of water contaminants," Nature Biotechnology, vol. 38, no. 12, pp. 1451–1459, (2020).
- [15]. A. M. Q. K. Al-Asadi, K. S. Muttair, A. G. Wadday, and M. F. Mosleh, "Wireless body-area network monitoring with ZigBee, 5g and 5g with MIMO for outdoor environments," Bulletin of Electrical Engineering and Informatics, vol. 11, no. 2, pp. 893–900, (2022).
- [16]. V. K. Jhunjunwala, T. Ali, P. Kumar, P. Kumar, P. Kumar, S. Shrivastava, and A. A. Bhagwat, "Flexible UWB and MIMO antennas for wireless body area network: A review," Sensors, vol. 22, no. 23, p. 9549, (2022).
- [17]. Bui Tien Anh, Do Thanh Quan, Pham Thanh Hiep, "Developing the max-min power control algorithm for distributed wireless body area networks", AEU - International Journal of Electronics and Communications, vol. 158, pp. 154448, (2023).
- [18]. H. Q. Ngo, A. Ashikhmin, H. Yang, E. G. Larsson, and T. L. Marzetta, "Cell-free massive MIMO versus small cells," IEEE Transactions on Wireless Communications, vol. 16, no. 3, pp. 1834–1850, (2017).
- [19]. M. B. Majed, T. A. Rahman, O. A. Aziz, M. N. Hindia, and E. Hanafi, "Channel characterization and path loss modeling in indoor environment at 4.5, 28, and 38 GHz for 5g cellular networks," International Journal of Antennas and Propagation, vol. 2018, pp. 1–14, (2018).

## TÓM TẮT

### **Phát triển thuật toán điều khiển công suất truyền dữ liệu đường xuống cho mạng vô tuyến quanh cơ thể hợp tác**

Mạng vô tuyến quanh cơ thể (WBANs - Wireless Body Area Networks) hiện nay đang thu hút sự quan tâm và nghiên cứu của các nhà khoa học với rất nhiều ứng dụng tiềm năng trong lĩnh vực quân sự, y tế, cứu hộ cứu nạn, thể thao, giải trí và đặc biệt là trong theo dõi, chăm sóc sức khỏe từ xa. Trong bài báo này, các tác giả đề xuất một mô hình WBANs mới, gọi là 'WBANs hợp tác', với điểm khác biệt so với mô hình truyền thống là các cảm biến truyền và nhận dữ liệu trực tiếp từ các điểm truy cập (AP - Access Point) mà không thông qua bộ điều phối. Các tác giả cũng phát triển thuật toán điều khiển công suất truyền dữ liệu đường xuống từ AP đến cảm biến. Kết quả mô phỏng cho thấy rằng, khi áp dụng điều khiển công suất truyền dữ liệu, cảm biến đạt được thông lượng cao hơn so với trường hợp không điều khiển công suất, từ đó cải thiện chất lượng hệ thống.

**Từ khoá:** Mạng vô tuyến quanh cơ thể; Truyền dữ liệu đường xuống; Điều khiển công suất truyền dữ liệu; Ước lượng kênh.