Chapter

Resource Allocation in Wireless Body Area Networks: A Smart City Perspective

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Abstract

Healthcare is an essential service in smart cities. To deploy healthcare systems in such cities, personal health monitoring systems, infrastructure for collecting and delivering individual data, and a system for diagnosing symptoms are required. For the first requirement, wireless body area networks (WBANs) have recently received considerable attention from research communities. Owing to their main distinguishable features from general wireless sensor networks, research challenges regarding WBANs have been focused on network topology around the body and implanted nodes, efficient resource allocation, and power control. In this chapter, we provide a comprehensive discussion on the emerging research trends in the area of wireless sensor networks and a discussion of WBANs in terms of their resource allocation.

Keywords: wireless body area networks, resource allocation, radio resource control, transmission power control, smart city

1. Introduction

A smart city can be defined as a converged IT-based infrastructure that can provide information to civilians whenever required, as well as efficiently manage its elements as illustrated in **Figure 1**. As many studies have previously mentioned [1–3], the key technological needs of smart cities include the collection of diverse sensor' data and the monitoring and management of community services. In addition, there are five elements for a smart city based on the layer concept:

1. hardware infrastructure, that is, physical components, such as transportation and buildings;

2. sensors, that is, sensors and terminal nodes;

3. networks, that is, wired and wireless networks including WiFi and metropolitan area networks;

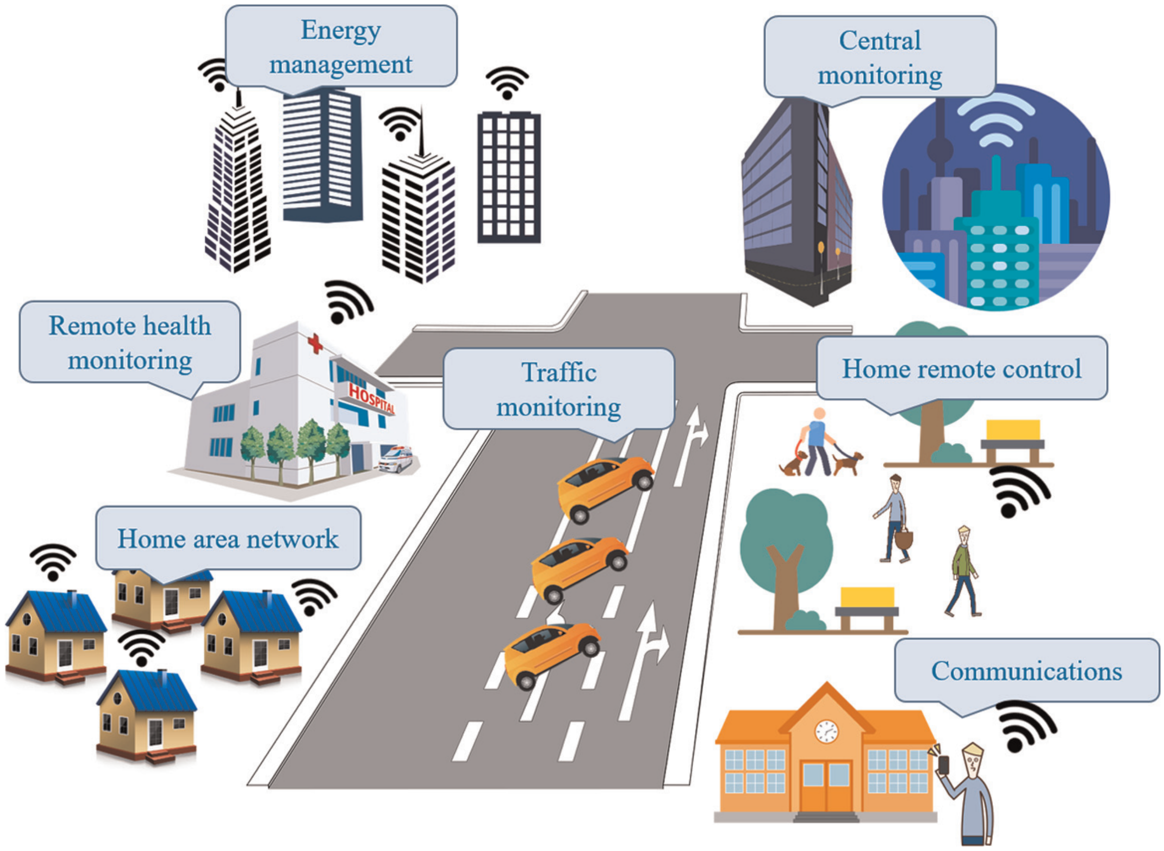


Figure 1.
Illustration of smart city architecture.

4. data and support, that is, application support through data collection, storage, and analysis;

5. applications, service elements, such as a smart economy, healthcare, education, and government.

Especially, applications combined with the Internet of Things (IoT) have been consistently mentioned in the smart city. They include city lighting, city transit, environmental and wastewater management, and privacy-preserving. Among these important services, healthcare is essential for efficiently collecting patient information and diagnosing any symptoms in a proactive way, as addressed in refs. [4, 5]. In addition, prompt treatment is also available from doctors without a direct examination through healthcare applications.

To deploy these services in a smart city, a personal health monitoring system and infrastructure networks are required. For the former, a new type of wireless sensor network called a wireless body area network (WBAN) has been proposed. In addition, IEEE 802.15.6 [6] has been established as an international standard for a WBAN.

In the aspects of telecommunications technology, WBAN is one of the special types of general wireless sensor networks in that wearable and implantable sensor nodes are supposed to detect and reports pre-determined events toward the sink node, called coordinator. In typical sensor networks, nodes are usually spatially distributed in the target area with a communications interface. This implies that they build the networks in an autonomous way. These tiny sensors naturally have resource problems, such as power consumption, limited computing capability, communication range, and available bandwidth. To protect the limitation of a sensor node, efficient and smart usage of available resources is more important than typical wireless networks.

Although a WBAN can be considered a type of wireless sensor network, its main features are significantly different from those of a general wireless sensor network (WSN) in that the sensor nodes are implanted or deployed on the body. This implies that a more careful network design should be taken such that the sensor nodes cannot harm the tissue of an individual through an increase in the temperature. In addition, more severe conditions for operations in WBANs require intelligent resource allocation to efficiently monitor and collect patients' health information. The main conditions to be considered for resource allocation in a WBAN are as follows:

1. Body movement: In a WBAN, the sensors are attached to the surface of, or inserted inside, the body; thus, body movement causes significant channel fading between the coordinator and sensor. Channel fading from body movement is referred to as body shadowing, and a device that aggregates physical data and transmits them to a medical server is called a coordinator. Because body shadowing causes packet loss, the link quality between the coordinator and the sensor is a key factor that should be considered for resource allocation.

2. Heterogeneous sensor types: Depending on the user's health condition, a WBAN can be composed of various types of medical sensors. In addition, the IEEE 802.15.6 standard specifies device priorities from 0 to 7 according to the application type. This means that a differentiated quality of service (QoS) must be guaranteed for a node collecting important body data; hence, resource allocation techniques must consider device priorities.

3. Non-rechargeable battery: Because most sensors are inserted into the body, it is difficult to replace or recharge their batteries. To extend the lifetime of a node, it is necessary to minimize the duty cycle or reduce resource waste owing to retransmission.

These conditions are the key factors distinguishing a WBAN from general sensor networks and have led to the development of network architecture and resource allocation techniques specialized for WBANs. In this chapter, we provide an overview of network architectures for WBANs and their design strategies. Next, we survey resource allocation techniques for WBANs and classify them into two categories—radio resource control and transmission power control. By clarifying their operating mechanisms and research objectives, we provide a comprehensive research trend and discussion of WBANs in terms of their resource allocation.

2. Overview of IEEE 802.15.6 based WBANs

In general, WBANs are specific networks for personal health monitoring, as illustrated in **Figure 2**. It is called intra-WBAN by being distinguished from inter-WBANs. The coordinator is located at the center of the body and is interconnected with the sensor nodes in a one-hop star topology. The coordinator aggregates the data received from the nodes and transmits them to the medical server through an external wireless network.

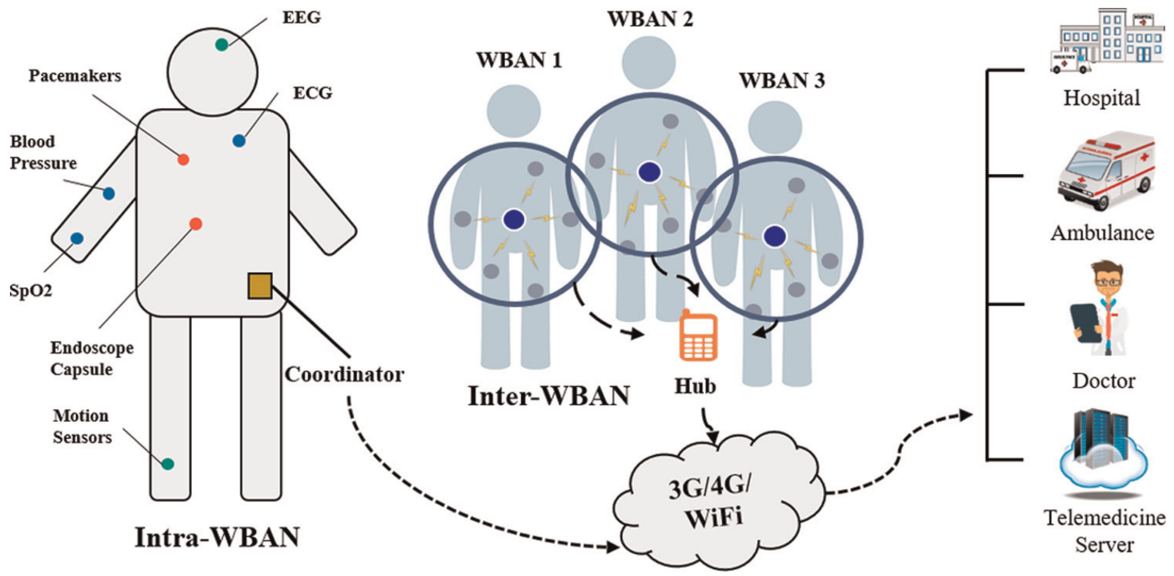


Figure 2.
Illustration of WBAN architecture.

The coordinator allocates available resources to nodes through centralized control. To manage the available resources, the IEEE 802.15.6 standard provides unique resource allocation mechanisms, such as association, access mode, and access phase. In this section, we provide an overview of the major components of the IEEE 802.15.6 standard used for resource allocation.

2.1 Access mode

According to the IEEE 802.15.6 standard, the coordinator operates in one of three access modes—beacon mode with superframes, non-beacon mode with superframes, and non-beacon mode without superframes. The coordinator can select an appropriate access mode considering the application requirements, channel conditions, and policy regulations to save available resources. It should be noted that the resource allocation techniques described in this chapter adopt beacon mode with superframes as the channel access mechanism.

2.2 Access phase

As shown in **Figure 3**, three types of access phases [i.e., random access phase (RAP), exclusive access phase (EAP) and managed access phase (MAP)] can be arranged in the superframe. Each node contends for channel acquisition in the RAP and EAP using carrier-sense multiple-access with collision avoidance (CSMA/CA). The contention window (CW) boundary in CSMA/CA is determined by a predefined value between and based on the device priority. As given in **Table 1**, the device

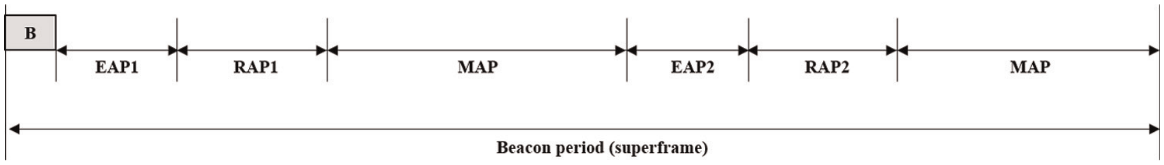


Figure 3.
Beacon mode with superframes.

Priority (0–7)	CW_{min}	CW_{max}
0	1	4
1	2	8
2	4	8
3	4	16
4	8	16
5	8	32
6	16	32
7	16	64

Table 1.
Contention window bounds for CSMA/CA specified in the IEEE 802.15.6 standard.

priorities for CSMA/CA are divided into eight levels (i.e., 0–7), giving a higher value to a node that collects important body data.

In RAP, all nodes are accessible, whereas only high-priority nodes can access EAP. In MAP, the coordinator can contain scheduled uplink allocation intervals, scheduled downlink allocation intervals, and scheduled bi-link allocation intervals. To obtain a scheduled allocation interval, each node must establish an association with the coordinator. The association process is described in the following subsections.

2.3 Connection-oriented resource allocation

The IEEE 802.15.6 standard specifies that each sensor must notify its QoS requirements through an association with the coordinator. To establish an association, an unconnected node sends a connection request frame to the coordinator. The connection request frame includes the device priority and the requested number of timeslots. Upon receiving the connection request frame, the coordinator conducts timeslot scheduling and then notifies the scheduling information through a connection assignment frame.

After establishing an association, each node sends a data frame to the coordinator with the default output power. To change the scheduling information or adjust the transmission power level after the initial association, the coordinator unicasts the changed information to the corresponding node through a new connection assignment frame. Because the IEEE 802.15.6 standard does not define a specific header for transmission power control, the protocol designer must define a reserved space in the connection assignment frame to notify the transmission power level.

2.4 Acknowledgment policy

The IEEE 802.15.6 MAC supports two types of ACK policies to achieve energy-saving and scheduling efficiency. A source node can set the ACK policy field of the control frame. A receiver sends an immediate acknowledgment (I-ACK) or block acknowledgment (B-ACK) frame when it receives a data frame. For example, if the coordinator adopts the B-ACK mode, the control overhead and transmission delay for a continuous data stream can be reduced, whereas, in a situation in which packet loss owing to body shadowing frequently occurs, the I-ACK mode can improve the transmission reliability.

3. Resource allocation in WBANs

As described in the previous section, the IEEE 802.15.6 standard specifies the network architecture, access mode, and frame structure for WBANs; however, it does not define specific algorithms for radio resource control and transmit power control. To complement the IEEE 802.15.6 standard, various resource allocation techniques based on the IEEE 802.15.6 standard have been proposed. As previously described, they aim to satisfy the inherent constraints of a WBAN, such as body movement, heterogeneous sensor types, and non-rechargeable batteries. In this section, we classify the resource allocation techniques into radio resource control and transmission power control and then describe their operating mechanisms.

3.1 Radio resource control

In beacon mode with superframes, the coordinator can use time-division multiple-access (TDMA) or CSMA/CA as a channel access mechanism. In this subsection, we introduce TDMA-, CSMA/CA-, and hybrid-based approaches for allocating radio resources to sensor nodes.

3.1.1 TDMA-based approaches

Alam et al. [7] proposed an adaptive scheduling scheme to reduce idle energy consumption. To minimize energy waste through idle listening and overhearing, the coordinator creates a traffic register and records the sampling interval of the nodes. The coordinator then allocates a timeslot based on the sampling interval of the nodes using the traffic register. Each node can minimize the consumption of idle energy by waking up according to its own wake-up schedule.

In addition, Zhang et al. [8] proposed a data-rate-aware scheduling algorithm to improve energy efficiency. The authors pointed out that when allocating more timeslots to nodes with high data rates, a differentiated QoS can be supported; however, the energy is quickly consumed. To deal with this problem, the coordinator allocates the same number of timeslots to all nodes but adds additional timeslots to high-data-rate nodes when abnormal conditions are detected.

Ambigavathi et al. [9] proposed a priority-based scheduling technique to minimize delays in emergency data. Basically, the coordinator allocates timeslots in the order of device priority. The coordinator divides the data received into low- and high-threshold data to guarantee a differentiated QoS for emergency data occurring at runtime. The coordinator then preferentially allocates timeslots to a node with a higher criticality among nodes with the same device priority.

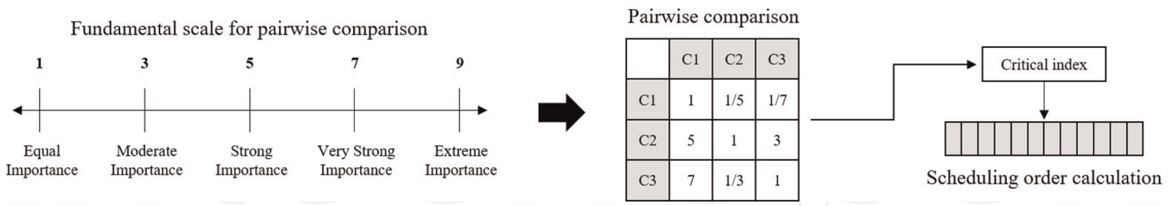
Liu et al. [10] also proposed a dynamic scheduling technique to reduce the packet loss owing to body movement. The authors used a Markov decision-making process to recognize body movement. The proposed Markov model is defined in two states, that is, a “good state” and a “bad state.” Each state is determined based on the link quality between the coordinator and the sensor. For example, a good state indicates that the transmission has been successful, and a bad state indicates that the transmission has failed. For each TDMA round, the coordinator preferentially allocates timeslots to nodes in a good state.

Zhang et al. [11] proposed a dynamic scheduling technique using temporal autocorrelation to reduce the packet loss owing to body shadowing. The authors pointed out that when defining the state of an on-body link as good or bad, the channel condition cannot be accurately recognized. To overcome this limitation, the proposed scheme predicts the channel condition in the next TDMA round after analyzing the temporal autocorrelation using historical data on the link quality. The coordinator then preferentially allocates timeslots to nodes with high autocorrelation coefficients because the higher the autocorrelation coefficient, the more uniform the movement pattern.

Kim et al. [12] proposed a scheduling order optimization technique using multiple cognitive metrics to achieve multi-objective optimization, such as a differentiated QoS and energy saving. The authors used the multi-criteria decision-making (MCDM) method [13] to combine the three cognitive metrics (i.e., packet error rate, power consumption ratio, and user priority) into a single metric called the critical index. Specifically, the proposed MCDM model derives a weighted normalized value (i.e., critical index) after determining the relative importance of multiple metrics through a pairwise comparison matrix. As shown in **Figure 4**, the pairwise comparison matrix should be determined in advance by the decision-maker based on the network conditions. The coordinator then ranks the nodes based on the critical index and determines the scheduling order. A similar study was conducted by Roy et al. 1 [14].

Pushpan et al. [15] proposed an adaptive scheduling scheme to support energy efficiency and a differentiated QoS. As illustrated in **Figure 5**, the authors used fuzzy logic [16] to unify multiple cognitive metrics. The proposed fuzzy model uses the packet delivery ratio, energy consumption ratio, and buffer ratio as input values and normalizes them using linguistic terms (e.g., low, medium, and high). After defining a fuzzy inference rule through an if-else conditional statement, a fuzzy index can be derived. For example, a node with a “high” packet delivery ratio and “low” energy consumption ratio may acquire a higher fuzzy index using the fuzzy inference rule. The coordinator then determines the scheduling order based on the fuzzy index. Similar concepts can be found in refs. [17–19].

Chowdhury et al. [20] proposed a dynamic scheduling scheme to jointly improve the energy efficiency and network QoS. The authors derived the optimal scheduling policy through trial and error using Q-learning. The coordinator (i.e., agent) defines the state space as a combination of the sum rate and response time and the action



	C1	C2	C3
C1	1	1/5	1/7
C2	5	1	3
C3	7	1/3	1

Figure 4.
Scheduling order calculation using the MCDM method.

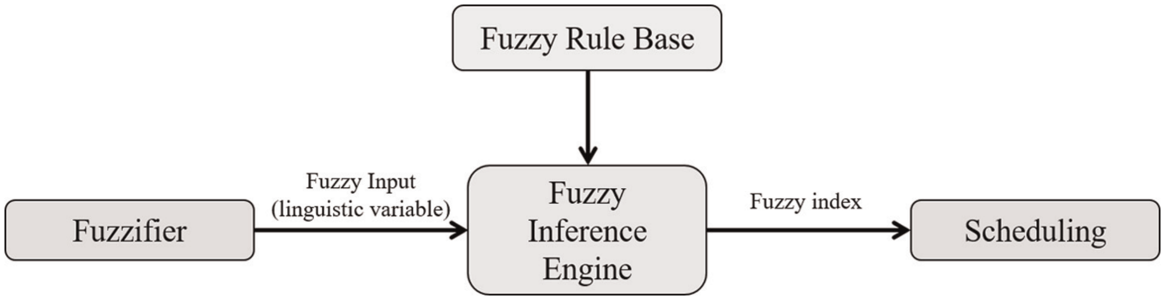


Figure 5.
Scheduling-order calculation using fuzzy logic.

space as the number of timeslots. The reward function is defined as a combination of the sum rate, response time, and average delay. The coordinator then finds a scheduling policy that maximizes the reward function while randomly allocating timeslots to nodes based on the epsilon-greedy algorithm (**Table 2**).

Chen et al. [21] proposed a joint optimization scheme using a deep Q-network (DQN). When a state space is defined through a combination of cognitive metrics, the coordinator has numerous state-action combinations. Thus, the scheduling technique using Q-learning has a problem in that the volume of the Q-table increases. To solve this problem, as shown in **Figure 6**, the authors used the DQN to learn the optimal scheduling policy. The proposed DQN model defines a state space as a combination of device priority, battery level, average delay, link quality, and access time as an action space. The reward function is defined as a combination of the energy consumption ratio, average delay, and received signal strength. The coordinator creates transitions using Q-learning and stores them in the replay memory. The coordinator then trains the neural network by randomly sampling transitions from this memory. Similar concepts can be found in refs. [22, 23].

3.1.2 CSMA/CA-based approaches

Saboor et al. [24] proposed a dynamic backoff algorithm for increasing the superframe utilization and energy efficiency. A typical binary exponential backoff

Reference	Research objective	Major consideration	Cognitive metric
[7]	Energy-saving	Heterogeneous traffic flow	Sampling rate
[8]	Energy-saving	Heterogeneous traffic flow	Abnormal condition
[9]	Differentiated QoS	Heterogeneous traffic flow	Traffic criticality
[10]	Energy-saving	Body shadowing	On-body link quality
[11]	Transmission reliability	Body shadowing	On-body link quality
[12]	Energy efficiency, differentiated QoS	Heterogeneous traffic flow, body shadowing	Packet error rate, priority, power consumption ratio
[15]	Energy efficiency, differentiated QoS	Heterogeneous traffic flow, body shadowing	Packet delivery ratio, energy ratio, buffer ratio
[20]	Energy efficiency, network QoS	Heterogeneous traffic flow, body shadowing	Sum rate, response time
[21]	Energy efficiency, differentiated QoS	Heterogeneous traffic flow, body shadowing	priority, battery level, delay

Table 2.
Summary of TDMA-based radio resource control.

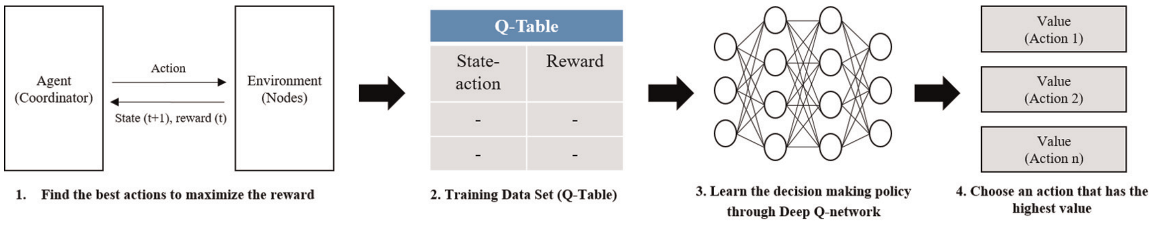


Figure 6.
DQN training for time-slot scheduling.

mechanism doubles the CW size when an even number of collisions occur; however, this mechanism reduces the superframe utilization. To solve this problem, the proposed backoff algorithm employs an additional sliding window. Specifically, the backoff number is randomly initialized within the range given in **Table 1**. If the channel is idle, the backoff number is decreased by 1, and when it becomes zero, the node transmits a data frame. If an even number of collisions occur, instead of doubling, it is replaced with the value of the sliding window. Here, the value of the sliding window was set to a non-overlapping value between the nodes. By using non-overlapping contention windows between nodes, the collision probability is reduced and superframe utilization is increased.

In addition, Fourati et al. [25] proposed a dynamic backoff algorithm to support a differentiated QoS. In a binary exponential backoff mechanism using the given CW size shown in **Table 1**, low-priority nodes have a longer waiting time when an even number of collisions occur. To solve this problem, the proposed algorithm uses a starvation index and continuously changes the CW boundary at runtime. Specifically, the starvation index is initialized to zero and increased by 1 when the channel is busy or retransmission occurs. If an even number of collisions occur, the CW boundary is recalculated based on the starvation index. By estimating the latency of a given packet, the proposed scheme can maintain a balance between low priority and critical traffic.

Mouzehkesh et al. [18] also proposed a dynamic backoff algorithm using fuzzy logic to improve the network reliability and overall latency. To ensure a balance between the channel condition and waiting time, the proposed fuzzy model uses the channel clear rate (CCR) and sample rate (SR) as input variables. The fuzzy inference rule gives a higher fuzzy index to a node having a “high” CCR and a “medium” SR. The backoff delay is then determined based on the fuzzy index.

Nekooei et al. [19] proposed a dynamic backoff exponent algorithm using fuzzy logic to increase the network reliability. The proposed algorithm represents the busyness of the channel as a backoff rate and calculates the backoff exponent using a combination of the history of the channel condition and the data rate of the node. Specifically, the backoff rate and data rate are used as the input variables for the fuzzy model. The fuzzy index is divided into four levels, and a node with the lowest fuzzy level has a relatively high probability of acquiring a channel (**Table 3**).

3.1.3 Hybrid-based approaches

Contention-free and contention-based approaches aim to improve the efficiency of radio resource control; however, their mechanisms have clear advantages and disadvantages. For example, although TDMA-based approaches can easily support a differentiated QoS, they cannot cope with packet loss owing to body shadowing. By

Reference	Research objective	Major consideration	Cognitive metric
[24]	Energy-saving	Heterogeneous traffic flow	Traffic priority
[25]	Differentiated QoS	Heterogeneous traffic flow	Starvation index
[18]	Transmission reliability	Heterogeneous traffic flow	Channel clear rate, sampling rate
[19]	Transmission reliability	Body shadowing	Number of backoff rate, data rate

Table 3.
Summary of CSMA/CA-based radio resource control.

contrast, CSMA/CA-based approaches do not guarantee a differentiated QoS, although they can increase the utilization of superframes. To overcome the limitations of individual approaches, hybrid-based approaches have been proposed.

Ramachandran et al. [26] proposed a link-quality-aware hybrid MAC protocol. The authors argue that body shadowing itself occurs instantaneously; however, the effectiveness of shadowing increases when the body is active for a long period of time. This effect weakens the communication between the implantable sensor nodes, increasing the likelihood of missing life-critical data. In the proposed scheme, the nodes are classified as high- and low-priority nodes. The superframe is divided into three parts: EAP, RAP, and MAP. In MAP, the coordinator decides to apply TDMA to high-priority nodes, whereas low-priority nodes use EAP and RAP. The proposed scheme uses the received signal strength indicator (RSSI) and packet delivery ratio to predict the dynamics of human activity to improve reliability and energy efficiency. In a TDMA period, the coordinator preferentially allocates a timeslot to a node that has a high packet delivery ratio and moves periodically. In addition, long-term body shadowing increases the chances of missing life-threatening medical data and can increase latency. The authors argue that most medical sensors are unable to significantly increase the output power, and thus temporarily using a relay node may be the optimal solution to overcome this situation. In the proposed scheme, the relay node is used when a low packet delivery ratio is detected; otherwise, it is disabled. This relaying mechanism reduces unnecessary energy waste.

Choi et al. [27] proposed an energy-efficient hybrid MAC protocol. The superframe structure of the IEEE 802.15.6 standard consists of EAP, RAP, and MAP. The authors pointed out that the nodes are always active in MAP, resulting in constant energy consumption. To solve the energy waste problem, the proposed mechanism aims to minimize the MAP length. Specifically, EAP2 and RAP2 are arranged after EAP1 and RAP1, and MAP is arranged at the end of the superframe. If a node finishes its transmission in EAP1, it can go into sleep mode to save energy. Each node provides transmission information to the coordinator such that it can synchronize with all nodes.

Wang et al. [28] proposed a dynamic MAC protocol. With the proposed mechanism, the superframe is divided into RAP and MAP, and the lengths of the two phases are dynamically adjusted according to the data rate and data type. Note that CSMA/CA is used in RAP, whereas TDMA is used in MAP. The coordinator allocates timeslots to nodes in the MAP based on the device priority; that is, high-priority nodes have more timeslots. Nodes with no data to send in the buffer save energy by entering a sleep state. Specifically, three priority levels are defined, from 0 to 2, depending on the criticality. A node that has a high data rate and generates emergency data is given priority 0, whereas normal nodes are given priority 2. Initially, the coordinator gives all nodes the highest priority and then sets the threshold ratio to adjust the priority. If the data rate of a node is greater than the threshold, it is classified as a high-priority node, and the remaining nodes are classified as normal nodes. The threshold value was adjusted dynamically to accommodate heterogeneous traffic. To support a differentiated QoS, the coordinator grants a small range of CWs to the node with the highest priority.

Huq et al. [29] proposed a hybrid MAC protocol to provide a differentiated QoS. The propagation of emergency messages requires high reliability and minimal channel access delays. The authors pointed out that neither RAP nor EAP can be used for emergency traffic because of the potential for data loss owing to channel collisions. To address this issue, the proposed scheme dynamically inserts a listening window within

Reference	Hybrid type	Major consideration	Cognitive metric
[26]	TDMA + CSMA/CA	Heterogeneous traffic flow, body shadowing	Device priority, RSSI, packet delivery ratio
[27]	TDMA + CSMA/CA	Heterogeneous traffic flow	Device priority
[28]	TDMA + CSMA/CA	Heterogeneous traffic flow	Criticality
[29]	TDMA + CSMA/CA	Heterogeneous traffic flow	Device priority

Table 4.
Summary of hybrid-based radio resource control.

a contention-free period (MAP). The frequency of the insertion of the listening window was determined by the minimum delay tolerance. The proposed scheme also uses idle timeslots to insert an additional listening window for emergency traffic without impacting the network throughput. Emergency devices can use guaranteed access periods to send data in the listening window without notifying their QoS requirements to the coordinator. This process can improve the reliability and access times. Note that the duration of the access phase is dynamically adjusted based on the QoS requirements of each node (**Table 4**).

3.2 Transmission power control

Quwaider et al. [30] proposed a body-posture-based transmission power control scheme to strike a balance between energy consumption and reliable transmission. Specifically, the authors proposed a dynamic posture position inference algorithm that recognizes the current posture position using on-body link characteristics. The proposed system infers the current body posture based on RSSI measurements on the receiver side. In addition, the authors set a range of RSSI thresholds to balance a reliable transmission and energy consumption through quantitative experiments based on a real WBAN testbed. The proposed algorithm recognizes the current body posture by defining the relationship between the power-level index and RSSI as a linear equation. Once the linear equation for the new position is obtained, the optimal transmission power level can be derived (**Table 5**).

Zang et al. [31] proposed an accelerometer-assisted transmission power control algorithm to improve energy efficiency. The authors pointed out that energy-efficient communication can be achieved by optimizing the output power required for successful transmission. The existing approaches determine the transmission power level based on the received signal strength; however, there is a possibility that the current link information is already out of date owing to dynamic on-body link conditions. To

Reference	Research objective	Major consideration	Cognitive metric
[30]	Energy-saving, transmission reliability	Body shadowing	Gait-cycle
[31]	Energy-saving, transmission reliability	Body shadowing	Gait-cycle
[32]	Energy-saving, transmission reliability	Body shadowing	On-body link quality
[33]	Energy-saving, transmission reliability	Body shadowing	On-body link quality

Table 5.
Summary of transmission power control techniques.

solve this problem, the authors used periodic link-quality fluctuations. The proposed algorithm defines the relationship between body posture and channel periodicity and then recognizes the current body movement using an accelerometer. This means that the acceleration signal and received signal strength of the packet have the same cycle. Each node then sends a packet with the minimum output power when the link quality is the best or increases the transmission power level using feedback information to prevent a delay violation.

Zhang et al. [32] proposed a joint transmission power control and scheduling scheme to provide a flexible trade-off between transmission reliability and energy consumption. Initially, each node is assigned its own scheduled uplink interval (SUI) with the same number of timeslots to satisfy the fairness constraint. To avoid packet loss from body movement, the authors proposed a temporal autocorrelation model in which the coordinator tracks the link conditions of all sensor nodes based on the RSSI measurements and predicts the channel state in the next TDMA round. The coordinator uses the predicted channel conditions to adjust the SUI order and the transmission power level. For example, the coordinator rearranges the SUI according to the node-link quality to increase the probability of successful transmission. In addition, the output power is determined to be higher than the reception sensitivity, considering the channel fluctuations in the next TDMA round.

Finally, Zhang et al. [33] proposed a relay-aided transmission power control scheme to increase transmission reliability and energy efficiency. The authors pointed out that the transmission power level should be adaptively adjusted to cope with changes in the on-body link conditions. The coordinator recognizes the channel state using the RSSI records of the packets received in the previous TDMA round. The coordinator then calculates the optimal transmission power level required for successful transmission based on the channel state and informs the transmission power level to nodes through a beacon frame. In addition, the authors proposed an adaptive transmission scheme using a relay node to improve the reliability of transmission. If the current channel condition between the coordinator and the source node is expected to be bad, the coordinator notifies the source node to apply a relay-assisted two-hop transmission.

4. Research challenges

In this section, we present further research challenges and open issues in resource allocation in WBANs.

4.1 Advanced/smart resource management for multi-objective optimization

This chapter introduced various resource management techniques to achieve specific objectives (i.e., differentiated QoS, reliability, and energy-saving). Most approaches aim to achieve a single objective; however, WBANs include serious restrictions different from general WSNs and thus must satisfy different service requirements simultaneously. Therefore, it is important to provide flexible trade-offs between optimization criteria rather than achieving a single-objective optimization. That is, advanced/smart resource management techniques that can adaptively make decisions according to changes in network conditions are required to achieve multi-objective optimization.

4.2 Reliable simulation systems

Various resource management techniques have been proposed to satisfy the service requirements of WBANs; however, the development of simulation systems to verify their performance has not been adequately followed. Although some simulation tools (e.g., OMNet++, OPNET, and NS-3) for building a WBAN environment have been proposed, they do not provide the necessary middleware or framework to import the latest technologies (e.g., DRL). The lack of a simulation system is a major factor in reducing the reliability of modern resource management schemes; hence, the development of reliable simulation systems remains one of the challenging tasks in WBANs.

4.3 Deployment for real WBAN system

To satisfy the service requirements of WBANs, various resource management techniques have been proposed in intra-WBANs. However, for the proposed mechanisms to be applied to an actual WBAN system, it is necessary to solve the mutual interference problem between adjacent WBANs in a public place. In addition, a unified network architecture conforming to the IEEE 802.15.6 standard is required to improve the scalability of the resource management techniques; however, most resource management schemes did not consider the IEEE 802.15.6 standard. Hence, bridging the performance gap between a simulation system and a real WBAN system by fully complying with the specifications presented in the IEEE 802.15.6 standard is one of the major challenges in WBANs.

4.4 Security

It is essential to provide high-level security services because WBANs collect physiological data of the human body. The IEEE 802.15.6 standard specifies encryption algorithms (e.g., DES and AES) that can be used at the MAC level, and thus protocol designers should implement a security model to protect private data. However, these encryption algorithms are outdated to defend against various types of attacks. Therefore, it is necessary to develop a simple and effective security model that can respond to various types of attacks considering the limited resources of WBANs.

5. Conclusions

A WBAN has unique characteristics that distinguish it from general wireless sensor networks, which has led to the development of new network architecture and resource allocation technique. In particular, resource allocation techniques have become increasingly intelligent to meet the significant constraints of WBANs. In this chapter, we provided comprehensive research trends and a discussion of WBANs in terms of resource allocation. Specifically, we first introduced the network architecture of a WBAN and outlined the major components of the IEEE 802.15.6 standard used for resource allocation. Next, we classified the resource allocation techniques into radio resource control and transmission power control and then described their operating mechanisms.

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Conflict of interest

The authors declare no conflicts of interest.

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