UNIVERSITI TEKNOLOGI MARA

HYBRID QL-DT MAC: LIGHTWEIGHT DECISION TREE MODEL FOR PREDICTING Q-LEARNING-BASED ADAPTIVE SLOT ALLOCATION IN MEDIUM ACCESS CONTROL PROTOCOL FOR WIRELESS BODY AREA NETWORKS

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ABSTRACT

Wireless Body Area Networks (WBANs) have gained significant attention in e-healthcare applications due to their ability to provide continuous and cost-effective monitoring of physiological parameters. Standardized under IEEE 802.15.6, WBANs comprise low-power and lightweight sensor nodes deployed on, around, or within the human body to support real-time healthcare services. The performance of WBANs is determined by the Medium Access Control (MAC) protocol, which regulates channel access, slot allocation, and traffic prioritization. However, existing MAC protocols, including IEEE 802.15.4 and IEEE 802.15.6, often rely on static or insufficiently adaptive slot allocation mechanisms, resulting in inefficient resource utilization, increased higher packet delay, excessive energy consumption, and degraded Quality of Service (QoS) under dynamic and heterogeneous traffic conditions. To address these challenges, this thesis proposed a Hybrid QL-DT MAC protocol for adaptive slot allocation in WBANs under periodic and emergency traffic conditions. The proposed protocol integrated Q-Learning (QL) and a Decision Tree (DT) model to provide intelligent, lightweight, and real-time scheduling decisions. Simulated datasets generated using Castalia in the OMNeT++ environment were employed to design, train, and evaluate the proposed model under realistic WBAN operating conditions. The framework operated in two stages. In the offline stage, QL learned optimal slot allocation policies through interactions with the network environment. Subsequently, the acquired knowledge was used to train a DT model that performed rapid online scheduling decisions with lower computational complexity. The adaptive scheduling mechanism dynamically allocated transmission opportunities based on traffic priority, buffer status, and channel conditions through a reinforcement-based reward structure. The performance of the proposed protocol was evaluated in terms of Packet Delivery Ratio (PDR), packet delay, throughput, and energy consumption. Simulation results demonstrated that the proposed Hybrid QL-DT MAC consistently outperformed benchmark MAC protocols across all performance metrics. The protocol achieved a packet delay reduction of up to 97.6%, improvements of up to 85.8% in PDR, and a throughput increase of up to 98.2%. Furthermore, overall energy consumption was reduced by approximately 75.9%, indicating significant improvements in network efficiency and QoS provisioning. The contribution of this research is the development of a hybrid learning-based MAC framework that combines the adaptive capability of QL with the fast inference and low computational complexity of DT for resource-constrained WBANs. The study was limited to simulation-based evaluation in a single-hop WBAN topology under periodic and emergency traffic scenarios. Future research may focus on real-world implementation, security integration, and scalability assessment in larger healthcare monitoring environments.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

In recent decades, healthcare systems worldwide have faced increasing pressure due to the rapid growth of the elderly population and the rising prevalence of chronic diseases, such as cardiovascular disorders, diabetes, kidney disease, and cancer [1], [2]. These conditions are major contributors to global mortality and healthcare expenditure [3]. The World Health Organization (WHO) predicts that by 2030, diabetes alone will be among the leading causes of death, consuming up to 15% of national healthcare budgets in some countries [3]. Demographic trends exacerbate this burden, with the global population aged 60 and above expected to exceed 20% by 2050, and even higher proportions in countries like Japan and the United Kingdom [4]. These shifts necessitate a transformation in healthcare delivery, moving from reactive treatment toward proactive, continuous monitoring, early diagnosis, and preventive care

Digital health technologies have emerged as key solutions to these challenges, particularly systems enabling remote patient monitoring through interconnected medical sensors [5]. Among these, Wireless Body Area Networks (WBANs) play a pivotal role, consisting of miniature, low-power sensor nodes deployed in, on, or around the human body [6], [7]. WBAN sensors continuously monitor physiological parameters, including heart rate, body temperature, blood pressure, oxygen saturation, glucose levels, and muscle activity, and transmit the data wirelessly to a coordinator node or remote server for real-time analysis and clinical decision-making [8] ,[9]. By eliminating the constraints of wired medical devices, WBANs improve patient mobility, comfort, and quality of life while enabling continuous health surveillance [10].

Advances in information and communication technology (ICT) have further facilitated WBAN adoption by supporting reliable wireless communication, real-time analytics, and intelligent health assessment [11]. These developments contribute to improved life expectancy and reduce chronic disease burden [12]. However, WBANs remain resource-constrained, with sensor nodes limited by battery capacity, processing power, and memory [13]. Since sensor nodes are the main energy consumers, efficient