



**Duty Cycle Optimization Using Game Theory Two  
Master Nodes Cooperative Protocol in Wireless Body  
Area Networks**

by

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## LIST OF ABBREVIATIONS

5G	Fifth generation (5G)
ABEB	Alternative Binary Exponential Backoff (ABEB)
AF	Amplify-and-Forward (AF)
AP	Access point (AP)
ARQ	automatic repeat request (ARQ)
BAN	Body Area Network (BAN)
BER	Bit Error Rate (BER)
BSN	Body Sensor Networks
BO	Backoff counter (BO)
CA-MAC	Collision Avoidance -Medium Access Control
CAP	Contention Access Period (CAP)
CCA	Clear channel assessment (CCA)
CCS	Cooperative Compressed Sensing
CDC	Coordinate Duty Cycle (CDC) technique
CEH	Cooperative Energy Harvesting (CEH)-MAC
CM	Channel Model (CM)
CM3	Channel Model 3
CMR	Cooperative Multi-Path Routing
CLDO	Cross-Layer Design Optimal
CN	Coordinator node (CN)
CO-LAEEBA	Cooperative- Link Aware and Energy Efficient procedure for wireless Body Area networks
CSMA/CA	Carrier-Sense Multiple-Access with Collision Avoidance
CW	Contention Window (CW)

D8PSK	Differential 8-Phase-shift Keying (D8PSK)
DBPSK	Differential Binary Phase Shift Keying (DBPSK)
DC	Duty cycle (DC)
DF	Delay-and-Forward (DF)
DMQoS	Data-Centric Multi Objective Quality of Services
DPSK	Differential Phase shift Keying (DPSK)
DQPSK	Differential Quadrature Phase shift Keying (DQPSK)
DRA	Dynamic Routing Algorithm (DRA)
DTS	Dynamic time slot
EE	Energy efficiency (EE)
EETP	Energy Efficient Traffic Prioritization For Medium Access Control (EETP-MAC)
EFC	Electrostatic Field Communication (EFC)
E-OCER	Extended-OCER (E-OCER)
EPR	Energy- aware Peering Routing protocol
GMSK	Gaussian Minimum Shift Keying (GMSK)
HBC	Human Body Communication (HBC)
HPR	Hotspot Preventing Routing Algorithm
IC	Index of Critical Data
InCo-CEStat	Incremental Cooperative Critical Data Transmission in Emergencies for Static WBAN (InCo-CEStat)
IoT	Internet Of Thing
IoMT	Internet Of Medical thing
JRP	Joint Relay Selection and Power Control Scheme (JRP)
LAEEBA	Link Aware and Energy Efficient procedure for wireless

Body Area networks

LBT	Listen –before – Transmit (LBT)
LDC-MAC	Low Duty Cycling MAC (LDC-MAC)
LOAD	The 6LoWPAN Ad-Hoc On-Demand Distance Vector Routing protocol
LTDA-MAC	low-delay traffic-adaptive medium access control LTDA-MAC
M2M	Machine to Machine (M2M)
MAC	Medium Access Control (MAC)
MEM	MEM-MAC
MRC	Maximal Ratio Combining (MRC)
MMPQoS	Multi-agent Markov Probable
MWCA	Multi hop WBAN Configuration Approach (MWCA)
NB	Narrow Band (NB)
NPCG	Non Cooperative Game theory (NPCG)
OBN	On belt master node (OBN)
OCER	Optimized Cost Effective and Energy Efficient
OMN	Outer master node (OMN)
ORPL	Opportunistic Routing Protocol
PA-MAC	Priority-Based Adaptive MAC Protocol (PA-MAC)
PCLMAC	Priority Cross Layer Medium Access Channel protocol (PCLMAC)
PCLRP	Priority-based Cross Layer Routing Protocol (PCLRP)
PDA	Personal Digital Assistant (PDA)
PEH-QoS	Power QoS (PEH-QoS)
PER	Packet error rate (PER)
PER	Probability error rate (PER)
PFB	Prioritized Fibonacci backoff

PHY	Physical Layer
PPDU	Physical Layer Protocol Data Unit
PSDU	Physical Layer Service Data Unit
PU	Primary User
QoS	Quality of service
RL-CAA	Reinforcement Learning—Channel Assignment Algorithm
RLNC	Random Linear Network Coding
SCP	Scheduled Channel Polling
TARA	Temperature Aware Routing Protocols
TERP	Trust and Energy Aware Routing Protocol
TMP	tele-medicine protocol
UWB	Ultra Wide Band
WASP	Wireless Area Sensor Personal
WBASN	Wireless Body Area Sensor Networks

## LIST OF SYMBOLS

BC	Backoff time varies from 1 to CWmin
BER	Bit Error Rate
c	The price of the time for leasing the spectrum to CDU by WS and it is determined by WS users
CI	The criticality index
CWmax	The maximum contention window and vary from 4 ~ 64
CWmin	Minimum contention window and vary from 1 ~ 16
D	The candidate node-set
$E_{tr}$	Energy
$E_{tx}$	$E_{tx}$ and $E_{rx}$ are the energies required for the transmitter and receiver energies in transmitting and receiving one bit
$+ Pt/R$	
$E_{tr,data}^{TMNCP}$	Total energy consumed in the transmission of a data packet with TMNCP
OBN	On body communication
$P_i$	The cooperative power of $CDU_i$
$P_i^*$	The optimal non-cooperative game of cooperative communication
$P_{length}$	Packet length
$P_t$	Transmission power
$P_s$	The transmission power from the CDU user to the WBAN CN
R	Maximum number of retransmission retrying
$R_{cdu}$	The transmission rate of the CDU network
$T_{active}$	
$T_{sleep}$	Sleep time
T	Total time to transmit packet
$T_s$	CSMA slot length
$T_p$	Preamble time
$T_c$	Collision time, $T_c = T$
$T_{PHY}$	Physical Header Time
$T_{on}$	RF transceiver power-on start time
$T_{MAC}$	MAC header

$T_{CW}$	Average backoff time
$T_{BODY}$	MAC frame body time
$T_{data}$	Time to transmit a data packet
$T_{FCS}$	Frame check sequence time
$T_{ACK}$	Time to receive an immediate acknowledgment packet
$\tau$	Transmission probability
$U_{CDU}^i$	The utility of $CDU_i$
$\eta$	Path loss

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## **Pengoptimuman Kitaran Tugas Berasaskan Teori Permainan Pada Dua Titik Induk Berprotokol Di Dalam Rangkaian Tanpa Wayar**

### **ABSTRAK**

Rangkaian Tanpa Wayar WBAN adalah rangkaian komunikasi sensor (dan / atau penggerak) yang diletakkan di dalam, atau mungkin di sekeliling tubuh yang mewakili rangkaian kawasan generasi baharu yang menunjukkan perbezaan dan cabaran pelaksanaannya. Sensor WBAN adalah kecil, dan turut tertanam dengan sumber yang terbatas iaitu tidak berlaku dalam rangkaian sensor tradisional tanpa wayar (WSN). Pemindahan semula data berlaku disebabkan oleh pudar iaitu penyelewengan pelemahan yang memberi kesan isyarat ke atas media penyebaran tertentu dan perlanggaran adalah sumber utama tenaga yang terbuang. Oleh itu, bagi mengelakkan perlanggaran, kaedah yang digunakan untuk mencapai penggunaan kuasa yang lebih baik ialah meningkatkan BER. Dalam tesis ini, satu protokol baharu dari dua kerjasama protokol berasaskan nod utama telah dicadangkan untuk mengurangkan penghantaran semula data. Seterusnya dapat meningkatkan kebolehpercayaan dengan meningkatkan kitaran tugas yang mampu mengurangkan penggunaan BER dan kuasa. Oleh yang demikian, dicadangkan pengoptimuman kitaran tugas dalam Teori Permainan bagi dua kerjasama protokol yang dicadangkan untuk mengoptimumkan Kadar ralat bit (BER). Dalam protokol yang dicadangkan, dua nod induk dipertimbangkan, iaitu *nod master belt* dan nod induk badan luar. Bagi mengelakkan proses penghantaran semula oleh sensor yang disebabkan oleh pudar dan pelanggaran maka nod induk bekerja secara kerjasama diwujudkan bagi mengurangkan kadar ralat bit (BER), yang telah mengakibatkan pengurangan kitaran tugas dan purata penghantaran kuasa. Di samping itu, Model Matematik dalam kitaran tugas telah dibentangkan dengan protokol yang dicadangkan untuk WBAN. Dalam usaha untuk meningkatkan kitaran tugas maka satu kaedah yang efektif diperlukan untuk penghantaran dan menyalurkan data yang berkesan dalam merentas pelbagai laluan. Pendekatan Teoretik Permainan yang tidak sama telah dicadangkan, berdasarkan penggunaan mekanisme pajakan spektrum yang berasaskan harga, sementara terdapat penentuan bersama harga parameter  $c$  oleh sensor WBAN dan pengguna D2D. Semua pengguna kognitif terpilih (pengguna D2D) menggunakan kerjasama kuasa yang optimum dan mampu dipenuhi melalui kerjasama bukan permainan dalam kalangan mereka sendiri. Protokol yang dicadangkan diberi nama sebagai Teori Permainan berdasarkan dua nod induk protokol kerjasama komunikasi (GT-TMNCP). Hasil keputusan menunjukkan bahawa cadangan TMNCP mengurangkan BER dengan faktor 4. Seterusnya, purata daya penghantaran dikurangkan dengan faktor 0.21. Kitaran tugas dioptimumkan dan dipertingkatkan lagi dalam cadangan GT-TMNCP sebanyak 13%, pengurangan sebanyak 3 kali ganda berbanding dengan TMNCP, pengurangan penggunaan kuasa sebanyak 14% berbanding TMNCP bagi pembayangan dengan nilai 5 dB, IC=3 dan 5, mewakili data kritikal maksimum. Hasil keputusan juga menunjukkan bahawa BER juga berkurangan sehingga 8 kali ganda, kitaran tugas dioptimumkan sebanyak 8%, dan penggunaan kuasa sebanyak 7% bagi pembayangan 9dB, IC=7 berbanding dengan teknik pengoptimuman QoS. Ini menunjukkan potensi teknik yang

dicadangkan untuk digunakan pada sensor dan sistem tanpa wayar yang boleh digunakan pada masa hadapan.

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# Duty Cycle Optimization Based on Game Theory-Two Master Nodes Cooperative Protocol In Wireless Body Area Networks

## ABSTRACT

Wireless Body Area Networks (WBAN) is communication networks of sensors (and/or actuators) placed on, inside, or around the body that represent a new generation of personal area networks with different implementation challenges. WBAN sensors are small, and they are embedded with a finite source, which is not the case for traditional wireless sensor networks (WSN). Retransmission of data due to fading and collisions is the primary source of wasted energy, thus avoiding collisions is a technique that is used to achieve better power consumption and to reduce Bit Error Rate (BER). MATLAB is used in this thesis as a tool for computational programming. In this thesis, a new protocol of two master nodes-based cooperative protocol (TMNCP) is proposed to reduce data retransmission and improve reliability by improving duty cycle to reduce BER, power consumption and improve Energy efficiency. To optimize BER, power consumption, and duty cycle optimization Game Theory Two master nodes-based cooperative protocol (GT-TMNCP) is proposed. In the proposed protocol, two master nodes were considered, that is, the belt master node and the outer body master node. The master nodes work cooperatively to avoid the retransmission process by sensors due to fading and collision, reducing the bit error rate (BER), which results in a reduction of the duty cycle and average transmission power. In addition, a mathematical model of the duty cycle has been presented with the proposed protocol for the WBAN. In order to enhance duty cycle, an effective method of data-rate transmission which delivers the data across multiple paths effectively is required. A non-cooperative game theoretic approach has been proposed, based on the utilization of spectrum leasing mechanism that is pricing-based, while there is joint determination of the parameter price  $c$  (cost) by WBAN sensor and D2D users. All chosen cognitive users' (D2D users) utilised cooperative powers that is optimal and that is capable of being fulfilled through a non-cooperative game among themselves. The results show that the proposed TMNCP reduced the BER by a factor of 4 compared to the direct transmission model. The power consumption is reduced by a factor of 0.21 and energy efficiency is improved by 69% as compared to the direct transmission mode. Duty cycle is enhanced further in the proposed GT-TMNCP by 13%, leading to a reduction of BER by 3 times compared to TMNCP, and improved power consumption by 14% lower than TMNCP for shadowing 5 dB, Critical Index Data (IC) IC=3 and 5, representing maximum critical data. The results also exhibit that BER is reduced up to 8 times, Duty Cycle (DC) is enhanced by 8% , and Power consumption (PC) by 7% for shadowing 9 dB, IC=7 compared to QoS optimization approach and TMNCP. This shows the potential of the proposed technique to be used in future wearable wireless sensors and systems.

## CHAPTER 1 : INTRODUCTION

### 1.1 Research Background

Wireless body area network (WBAN) has emerged among the rising technologies due to its capability in monitoring health care and medical procedures, whereby its utilisation encompasses various fields, such as fitness, entertainment, medical personnel, rescue, and localisation. Known as self-organised network at the human body scale, it is made up of sensor nodes capable of distribution in, on, or around the human body (Yousaf et al., 2016). An example of WBAN operations can be seen in Figure 1.1. In general, human vital signs are sensed by the sensor nodes, which then process the data obtained and transfer them to the medical server of concern for treatment purposes. In such WBAN architecture, data can be gained either by physiological (e.g. electrocardiogram, electroencephalograph, and electromyography) or physical (i.e. via accelerometer and gyrometer) in nature; they are sensed in varying end nodes and disseminated via specific wireless links to the coordinator.

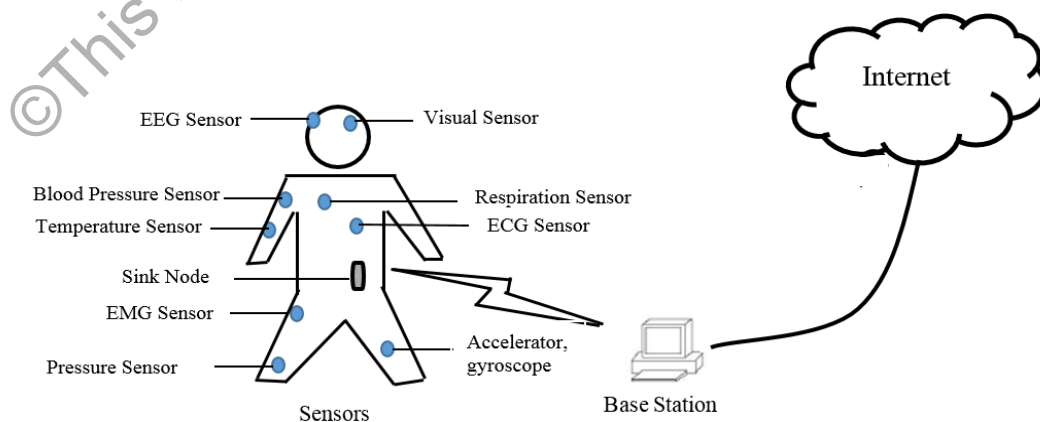


Figure 1.1 Typical Architecture of a WBAN

The importance of implementing wireless communication in the context of remote human body monitoring is undeniable as this type of monitoring should be unnoticeable, dependable, and cost-efficient. This allows the patients to fully experience the benefits of wireless technologies, which is attributable to the critical nature of certain data and the need for their delivery in a flawless or with minimal error as much as possible. Besides, cost is another key factor considered in mass-producing biomedical sensors that will be available for everyone (Movassaghi et al. 2014). To this end, sensors employed in WBAN are suggested to comprise smaller nodes and smaller-sized batteries relative to traditional wireless sensor networks (WSN). This particular battery feature limits sensor power consumption in sensing, handling, storing, and delivering the data, thus inevitably impacting the energy efficiency, throughput, and latency of the WBAN in general.

One of the requirements for WBANs is its ability for accurate and independent functions over an extended duration without needing battery charging. Accordingly, its major challenges towards achieving an improved network lifetime include designing an energy-efficient, power consumption, and dependable communication protocol (Yousaf et al., 2016). If achieved, it allows the incorporation of various technologies within a distributed intelligent system thus denoted as Cyber-Physical System (CPS), which is geared towards global data collection, central information processing, and local result dissemination (Z. Wang et al., 2015). Concurrently, a tightly-designed network topology in the context of dependable data transmission is highly necessary in WBANs as it can potentially counteract data loss and notable power wastage (Yousaf et al., 2016).