

ADAPTIVE IMPULSE-BASED ULTRA-WIDE BAND
WIRELESS ARCHITECTURE FOR ACHIEVING HIGHER
DATA TRANSMISSION RATES AND ENHANCING
RECEIVED SIGNAL QUALITY

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UNIVERSITI SAINS ISLAM MALAYSIA

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AUTHOR DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRAK

Band ultra lebar (UWB) berdasarkan impuls boleh digunakan untuk menyokong rangkaian tanpa wayar yang berbeza dengan kadar data yang berbeza dan kualiti isyarat yang terjamin jika denyutan yang dihasilkan ditala dengan berhati-hati. Kajian ini telah mencapai modaliti pengoptimuman dengan melihat dua aspek utama iaitu penghantaran data yang lebih tinggi dan kualiti isyarat penerima yang paling optimum. Penyelidikan ini bertujuan untuk mencapai pautan yang bijak dengan merealisasikan UWB yang lebih tinggi dengan kehilangan yang minima bagi Pemancar dan Penerima. Metodologi kajian telah menyiasat parameter fizikal bagi menghasilkan denyut yang sangat pendek dalam rangkaian frekuensi ultra-lebar. Ia mencadangkan reka bentuk templat pautan untuk tujuan mendapatkan sistem komunikasi IR-UWB yang bersesuaian. Sistem yang dicadangkan telah direkabentuk dan disimulasikan menggunakan MATLAB dan kadar ralat bit (BER) telah dinilai dengan menggunakan penerima RAKE yang sesuai yang menunjukkan peningkatan prestasi sebanyak 10% hingga 50%. Reka bentuk yang dicadangkan dengan jelas menggambarkan produktiviti hubungan komunikasi UWB dengan simulasi IEEE 802.15.4a UWB dalam persekitaran simulasi OMNET ++ - MIXIM dan IEEE 802.15.3a dalam MATLAB dan persekitaran pemodelan Simulink. Motif menggunakan persekitaran Simulink adalah untuk membentuk sama ada prototaip atau bukti-konsep dalam persekitaran simulasi masa. Status semasa piawaian komunikasi UWB dikategorikan dalam dua protokol IEEE utama iaitu IEEE 802.15.3a untuk tujuan kadar data yang tinggi menggunakan modulasi multiplexing pembahagian frekuensi ortogonal (OFDM) dan IEEE 802.15.4a untuk kadar data yang rendah menggunakan denyutan melompat masa (TH). Sumbangan kajian ini boleh dipertimbangkan bagi pengoptimuman IEEE802.15.4a supaya dapat menyokong serentak kadar data yang rendah dan tinggi serta menyokong dan mengekalkan kualiti isyarat yang diterima. Cabaran kajian ditentukan oleh keperluan untuk mencari satu penyelesaian UWB tunggal untuk menyediakan keupayaan sokongan terhadap kadar data yang berbeza bersama keperluan kualiti perkhidmatan (QoS). Kajian ini boleh dianggap sebagai bukti konsep penyesuaian PHY-MAC dalam reka bentuk dan seni bina UWB. Ini boleh dicapai dengan menala aliran denyutan yang dihasilkan melalui teknik spektrum penyebaran masa untuk memenuhi keperluan kadar data yang berbeza dan senario komunikasi QoS jarak jauh tanpa wayar. Satu penyelesaian UWB tunggal untuk kadar data yang berbeza dan keperluan QoS sangat wajar untuk mengurangkan kos membangunkan pelbagai penyelesaian UWB serta mengoptimumkan komunikasi di bawah persekitaran yang berubah secara dinamik. Dalam metodologi kajian ini, reka bentuk templat pautan untuk sistem komunikasi IR-UWB disimulasikan di mana prestasi isyarat yang diterima sebagai kadar ralat bit (BER) telah ditingkatkan sebanyak 10% hingga 50% menggunakan struktur penerima RAKE yang sesuai. Dapat disimpulkan bahawa penalaan parameter fizikal isyarat IR-UWB dengan nilai padanan yang terbaik untuk BER atau keperluan kadar data tertentu juga boleh meningkatkan BER sehingga 65%. Ini boleh ditunjukkan dalam senario simulasi terperinci dengan kadar data antara 20 Mbps hingga 200 Mbps, jarak maksimum 30 m dan keperluan BER tidak melebihi (10^{-2}) dengan modulasi denyutan ditetapkan ke 2-PAM. Dalam analisis simulasi masa nyata bagi paket yang diterima dalam senario dalaman dengan julat 12 m hingga 100 m menunjukkan bahawa, hasil terbaik diperolehi untuk kadar data antara 110 kbps hingga 6.8 Mbps. Hasil kajian yang diperolehi dapat menunjukkan bahawa prestasi komunikasi UWB yang terjejas masa boleh dipertingkatkan dengan ketara apabila parameter fizikal penjanaan denyut ditetapkan dengan betul dalam beberapa aplikasi dan kekangan model saluran.

ABSTRACT

Impulse-based ultra-wideband (UWB) can be utilized to support different wireless range with varied data rates and guaranteed received signal quality if the generated pulses tuned carefully. The unique physical advantages of generating a train of very narrow pulses (in nanoseconds) in ultra-wideband signal are proven in many literature studies to be utilized in different wireless sensing applications such as precise object tracking, high data rate wireless transmissions, medical radar imaging, and military intrusion detections. The motivations of this study can be understood as currently, UWB technology is standardized in two different IEEE protocols as IEEE 802.15.3a for high data rates using Orthogonal Frequency Division Multiplexing (OFDM) modulation and IEEE 802.15.4a for low data rates using time hopped modulated train of pulses. This study is motivated by the optimization of IEEE 802.15.4a to support higher rates as well as low rates, as also preserving the quality of the received signal. The problem statement of this research is inspired by the need to have a single UWB solution standard to be tuned to support different applications requirements of data rates and quality of service (QoS) instead of two different protocols. The proposal solution proves the concept of Adaptive PHY-MAC aware UWB design and architecture by tuning the generated train of pulses in time-hopping spread spectrum techniques to support the requirements of different data rates and QoS communications scenarios. The research methodology has investigated the physical parameters of generating a train of very short pulses in ultra-wide frequency ranges then, and it proceeds to propose link budget template design for the purpose of obtaining an adaptive IR-UWB communication system. The objective of this study is intended to utilize a single UWB solution for different data rates and QoS requirements, will reduce the costs of UWB applied over WSN, also will allow cognitively of the wireless node to maintain its operations under a dynamically changing environment in future scenarios. Proposed design of the link budget template for the adaptive IR-UWB communication system is simulated, and improvements are shown to be reached from 10 to 50% of the BER with the suitable RAKE receiver structure. Also, tuning the IR-UWB signal physical parameters with the best matching values for certain BER or data rates requirements can improve the BER up to 65%. Simulated scenarios results of data rates range from 20 to 200 Mbps with maximum distances of 30 m and BER requirement not exceeding (10^{-2}) showed that the best performance is achieved by tuning the pulse modulation to 2PPM. Real-time simulation analysis of the received packets in the indoor scenario of range between 12 to 100 meters, showed that the best-achieved throughput obtained for data rates between 110kbps to 6.8 Mbps. This proposed design clearly describes the productivity of the UWB communication link through the simulation of IEEE 802.15.4a UWB in OMNET-MIXIM and the IEEE 802.15.3a in MATLAB and SIMULINK. MATLAB coding is used to determine the data transmission measurable factors (i.e., parameters), and the SIMULINK is used as prototype proof-of-concept in a real-time simulation environment. The results showed that the performance of the time-hopped UWB communication could be enhanced significantly when properly choosing the setting of the physical parameters of the pulse generations under different applications and channel models constraints.

المخلص

يمكن استخدام النطاق العريض القائم على الدوافع (UWB) لدعم مجموعة لاسلكية مختلفة بمعدلات بيانات متنوعة، وجودة إشارة مضمونة إذا تم ضبط النبضات المتولدة بعناية. لقد حقق هذا البحث طريقة التحسين من خلال النظر في جانبيين رئيسيين هما: بيانات الإرسال الأعلى وجودة إشارة الاستقبال المثلى. ويهدف هذا البحث المقترح إلى الوصول إلى أعلى ميزانية ارتباط حيلة من خلال تحقيق أعلى UWB ضمن أقل المبادلات أهمية، وفيما يتعلق بالإرسال والاستقبال على التوالي. وقد درست منهجية البحث المعلومات المادية لتوليد قطار من النبضات القصيرة جدًا في نطاقات التردد الواسعة جدًا، ثم شرعت في اقتراح تصميم قالب ميزانية الوصلة بغرض الحصول على نظام اتصال IR-UWB قابل للتكيف. وتم تصميم النظام المقترح ومحاكاته باستخدام MATLAB وتقييم معدل خطأ البتات (BER) مع مستقبل RAKE مناسب مع تحسين نتائج الأداء بنسبة 10٪ إلى 50٪. يصف التصميم المقترح بوضوح إنتاجية ارتباط اتصالات UWB من خلال محاكاة IEEE 802.15.4a في بيئة محاكاة MIXIM - ++ OMNET و IEEE 802.15.3a في بيئة نمذجة MATLAB و Simulink. الدافع وراء استخدام بيئة Simulink هو تكوين نموذج أولي أو إثبات للمفهوم في بيئة محاكاة في الوقت الفعلي. يتم تصنيف الوضع الحالي لتقييم اتصالات UWB في بروتوكولين رئيسيين من IEEE 802.15.3a، وهما IEEE 802.15.4a لغرض معدلات بيانات عالية باستخدام تشكيل مضاعف تقسيم التردد المتعامد (OFDM) و IEEE 802.15.4a لمعدلات بيانات منخفضة باستخدام قافز الوقت (TH) قطار التضمين من القول. يمكن النظر في مساهمات هذا العمل من خلال تحسين IEEE 802.15.4a وذلك لدعم معدلات بيانات منخفضة وعالية في وقت واحد والحفاظ على جودة الإشارة المستلمة والحفاظ عليها. والتحديات التي تحددها ضرورة ضبط حل UWB واحد لتوفير الدعم تجاه معدلات بيانات مختلفة إلى جانب متطلبات جودة الخدمة (QoS). ويمكن اعتبار هذا الاقتراح بمثابة دليل على مفهوم تصميم وهندسة UWB المتوافقين مع PHY-MAC. ويمكن تحقيق ذلك عن طريق ضبط مجموعة النبضات المتولدة عبر تقنيات الطيف المنتشر. عبر الزمن لاستيفاء متطلبات معدلات البيانات المختلفة وجودة الخدمة لسيناريوهات الاتصالات اللاسلكية ذات المدى القصير. من المستحسن للغاية وجود حل UWB واحد لمعدلات بيانات مختلفة ومتطلبات جودة الخدمة من أجل تقليل تكاليف تطوير حلول UWB متعددة أيضًا، لتحسين الاتصالات في بيئات متغيرة ديناميكيًا. في منهجية البحث هذه، يتم محاكاة تصميم قالب ميزانية الوصلة لنظام اتصالات IR-UWB التكيفي، حيث تم تحسين أداء الإشارة المستقبلية كمعدل خطأ البتات (BER) بنسبة 10٪ إلى 50٪ باستخدام بنية مستقبل RAKE المناسبة. يمكن أن نخلص إلى أن ضبط المعلومات المادية لإشارة IR-UWB مع أفضل قيم مطابقة لمتطلبات معينة لنسبة الخطأ في البتات (BER) أو متطلبات معدل البيانات يمكن أن يحسن معدل BER بنسبة تصل إلى 65٪. يمكن إظهار ذلك في سيناريوهات محاكاة مفصلة مع معدلات بيانات تتراوح من 20 ميغابت في الثانية إلى 200 ميغابت في الثانية، ومسافة لا تزيد عن 30 متر ومتطلبات BER لا تتجاوز (10^{-2}) مع ضبط تشكيل النبض على 2-PAM. في تحليل المحاكاة في الوقت الفعلي للحزم المستلمة في السيناريو الداخلي بمدى يتراوح بين 12 و 100 متر، يظهر أنه تم الحصول على أفضل صبيب لمعدلات البيانات التي تتراوح بين 110 كيلو بايت في الثانية و 6.8 ميغابت في الثانية. ويمكن فهم أهمية النتائج التي تم الحصول عليها على هذا النحو، حيث يمكن تحسين أداء اتصالات UWB المتوقعة بشكل كبير عندما يتم تعيين المعلومات المادية لتوليد النبض بشكل صحيح ضمن تطبيقات معينة وقيود نموذج القناة.

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LIST OF SYMBOLS

α^2	Pulse Shaper
σ^2	The Variance
τ	Channel Delay
E_{Tx}	Transmitted Energy Per Pulse
E_{Rx}	Received Energy Per Pulse
A	Channel Gain
X	A log-normal Random Variable expressing the Channel Amplitude Gain
k-th	Multipath Contribution for n-th Cluster
τ_{nk}	Delay caused by K-th Multi-path Contribution within the n-th Cluster
ρ	Path Loss Exponent
Λ	Cluster Average Arrival Rate
λ	Pulse Arrival Rate
Γ	Power Decay Factor for Clusters
σ_g	Standard deviation of the channel amplitude gain
γ	Power Decay Factor within a Cluster
σ_ε	Standard deviation of the fluctuation of the channel coefficient for clusters
α_j	Amplitude of the j-th Transmitted Pulse
T_s	Average Pulse Repetition Period
φ_j	Time dithering associated with j-th Pulse.
τ_{nk}	Delay of k-th Path within n-th Cluster
D	Maximum Distance D that can be covered by Transmission
M	Modulation
N	Number of Generated Bits
P_{re}	Probability of Bit Error
B_f	fractional bandwidth
f_c	centre frequency
P_T	Transmitter power
L_S	The loss in the system
G_A	the gain of the antenna
τ	pulse duration
ν_f	power spectral amplitude of the signal spectrum
ν_t	the amplitude of the pulses
T	pulse repetition rate
$G(x)$	Gaussian pulse function
σ	standard deviation
T_p	pulse duration
τ_i	delay parameter
s_i	create pulses
T	represents time
$r(t)$	received signal
L	total resolvable multipath components
α_l	attenuation specific to the l-th path
A	maximum channel capacity (bits/second)
S	power of a signal (watts)
N	power of noise (watts)

λ	wavelength in meters
F	frequency (Hz)
T_C	Chip Time
f_H	higher frequency
f_L	lower frequency
$G(f)$	frequency domain of the Gaussian waveform
$s(t)$	transmitted signal
α	Pulse shaping
$n(t)$	Thermal noise
$P_0(t)$	normalized energy pulse waveform
C_g	Reference channel gain
ρ	path loss exponent
C	speed of light in a vacuum
$K(n)$	the number representing multipath contributions received by the n-th cluster
α_{nk}	channel coefficient of k-th multipath contribution for the n-th cluster
T_n	Time of arrival of the n-th cluster
E_{eff}	effective energy
PL_0	path loss at d_0
S	Shadow fading (log-normal)
σ_γ	The standard deviation of the path loss exponent
μ_0	Mean standard deviation of shadowing
μ_γ	Mean path loss exponent
σ_σ	The standard deviation of the shadowing
N_0	single-sided thermal noise spectral power density
E_r	received signal power
$P_s(f)$	double-sided power spectral density
$A_{FS}(f)$	free-space attenuation
E_b	average of bit energy
N_0	power density in AWGN channel
F_c	Sampling frequency
T_s	Frame time (Average pulse repetition)
N_s	Number of pulses per bit
N_h	The cardinality of the TH code
T_m	Pulse duration
τ	Shaping factor of the pulse
N_p	Period of the TH code

LIST OF ABBREVIATIONS

WSN	Wireless Sensor Network
QoS	Quality of Service
UWB	Ultra-Wideband
FCC	Federal Communications Commission
BER	Bit Error Rate
RF	Radio Frequency
CMOS	Carbon Metal Oxide Semiconductor
PAPR	Peak To Average Power Ratio
RFID	Radio Frequency Identification
IR	Impulse-Radio
PHY	physical layer
MAC	Media Access Control layer
PAN	Personal Area Network
LOS	Line Of Sight
NLOS	Non Line Of Sight
CM	channel model
EIRP	Equivalent Isotropic Radiated Power
GPS	Global Positioning System
DC	Direct Current
HDR	High Data Rate
WLAN	Wireless Local Area Network
LAN/MAN	Local Area Networks/ Metropolitan Area Networks
OFDM	Orthogonal Frequency Division Multiplexing
MB-OFDM	Multi-Band Orthogonal Frequency Division Multiplexing
DS	Direct Sequence
WPAN	Wireless Personal Area Network
ISI	Inter-Symbol Interference
PAM	Pulse Amplitude Modulation
PPM	Pulse position modulation
MIR-UWB	Multiband Impulse Radio Ultra-Wideband
AWGN	Additive White Gaussian Noise
PLL	Phase-Locked Loop
VCO	Voltage Control Oscillator
PA	Power Amplifier
ADC	Analogy To Digital Converter
LNA	Low Noise Amplifier
BB	Base Band
SoC	System On A Chip
PRR	Pulse Repetition Rate
RMS	Root Mean Square
PG	Pulse Generator
OOK	On-off keying
BPSK	Binary phase-shift keying
TH	Time Hopping
THSS	Time Hopping Spread Spectrum
CDMA	Code Division Multiple Access

OCC	Orthogonal Complementary Code
SV	Saleh-Valenzuela
SNR	Signal to Noise Ratio
RADAR	Radio Direction and Ranging
POS	Personal Operating Space
LR-WPAN	Low-Rate Wireless Personal Area Network
FFDs	Full-Function Devices
RFDs	Reduced Function Devices
MCMs	multiple-access schemes
DSSS	Direct Sequence Spread Spectrum
RFD	Reduced Function Device
ISM	Industrial, Scientific and Medical
U-NII	Unlicensed National information Infrastructure
RS	Reed-Solomon
PBTSs	Perfectly Balanced Ternary Sequences
TDMA	Time Division Multiple Access
GTS	Guaranteed Time Slots
CS	Carrier Sense
CCA	Clear Channel Assessment
LDR	Low Data Rate
CLOEE	Cross-Layer Optimization for Energy Efficiency
WBAN	Wireless Body Area Network
XLCU	Cross-Layer Control Unit
TM-MAC	Throughput Maximized MAC protocol
FPGA	Field Programmable Gate Array
SDR	Software-defined Radio
CW	Continuous Wave
NED	Network Description
IDE	Integrated Development Environment
GUI	Graphical User Interface
MAI	Multiple Access Interference
IR-UWB	Impulse Radio Ultra-Wideband
FB	fractional bandwidth
ML	maximum-likelihood
MRC	maximum ratio combining
PRI	pulse repetition interval
PN	Pseudo Noise
BPM	Bi-Phase Modulation
XML	Extensible Markup Language
PRF	Pulse Repetition Frequency
SHR	Synchronization Header
SFD	Start Frame Delimiter
NIC	Network Interface Card
PSD	Power Spectral Density
HDR	High Data Rate
AM	Amplitude Modulation
WiFi	wireless fidelity
OM	Okumura channel loss model
DSP	Digital Signal Processing