AN ENHANCED HYBRID SCHEME TO SUPPORT IP-BASED SMART OBJECT NETWORK

BY

WAN FARIZA WAN ABDUL RAHMAN

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International Islamic University Malaysia

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ABSTRACT

Smart object networks are potentially huge scale both in terms of the number of devices involved and the number of data generated by each device. IPv6 is the protocol of choice for smart object networks due to its features and readiness in providing an open and standard based technology for the endless number of applications. An IPv6 routing protocol for low-power and lossy networks (LLNs), known as RPL has been designed by Internet Engineering Task Force (IETF) for resource constrained smart objects. It is defined in RFC 6550 that RPL can support either Storing mode only or Non-Storing mode only. The main drawback of this idea is, a homogeneous Non-Storing mode RPL network will introduce a high level of communication overhead, and a homogeneous network of Storing mode RPL network will require too much memory resources. Frequent occurrence of loops in LLNs contributes to additional delay and memory consumption to buffer the packet. To address these problems, this thesis proposed an RPL enhancement scheme to support a hybrid mode RPL with consideration of loop-free repair. The implementation of loop-free local route repair in hybrid RPL can further reduce delay and memory constraint in handling loops while topology changes. In real-time applications such as smart health monitoring, the excessive delay is intolerable since it could affect the patient's life. The evaluation techniques used in this thesis are simulation using Cooja Contiki simulator and mathematical analysis. The feasibility of the proposed RPL enhancement is verified experimentally by developing a few scenarios of non-hybrid RPL (pure Storing and pure Non-Storing) mode as well as hybrid mode RPL of various percentage of Storing and Non-Storing. The performance metrics measured are memory consumption (in term of routing entries), total end-to-end delay and total routing overhead. Based on the simulation results, the memory consumption reduction in hybrid network integrated with loop-free repair achieves 25.22% to 33.9% compared to the homogeneous ones. The proposed scheme contributes to a better performance in terms of packet delivery ratio (PDR) compared to homogeneous Storing and homogeneous Non-Storing network but with an increased delay cost. Significant decrement of the routing overhead cost compared to homogeneous Storing and homogeneous Non-Storing scheme without loop-free repair mechanism can also be seen. The impact is not so obvious in a small size network. However, as the network grows, an improvement of up to 33.9% is achieved. In addition to simulation approach, mathematical analysis has been considered to measure performance metrics such as memory consumption (in bytes), total end-to-end delay and route discovery routing overhead.

خلاصة البحث

تعد شبكات الأجهزة الذكية من الشبكات واسعة النطاق من حيث عدد الأجهزة المتصلة وعدد البيانات التي يتم إنشاؤها بواسطة كل جهاز. بروتوكول الإنترنت/ الإصدار السادس (IPv6) هو البروتوكول المفضل لشبكات الأجهزة الذكية نظرًا لميزاته واستعداده لتوفير تقنية مفتوحة ومعيارية لعدد لا حصر له من التطبيقات. تم تعزيز بروتوكول توجيهIPv6 بإسم RPL للشبكات منخفضة الطاقة والخسارة (LLNs) بواسطة فريق هندسة الإنترنت (IETF) للتعامل مع الأجهزة الذكية المقيّدة الموارد. وكما تم تعريفه في RFC6550 فإن RPL يمكنه دعم وضع التخزين فقط أو وضع عدم التخزين فقط. العيب الرئيسي لهذه الفكرة هو أن شبكة RPL المتجانسة غير المخزنة ستقدم مستوى عالٍ من النفقات العامة للاتصالات، وستتطلب شبكة RPL المتجانسة ذات وضع التخزين الكثير من موارد الذاكرة. كما ان التكرار المستمر للحلقات في LLNs يساهم في المزيد من التأخير واستهلاك الذاكرة لتخزين الحزمة. لمعالجة هذه المشاكل، اقترحت هذه الأطروحة خطة تعزيز RPL لدعم وضع RPL مختلط مع الاخذ بالاعتبار إصلاح الشبكة بدون حلقة التكرار. حيث يمكن أن يؤدي تنفيذ إصلاح المسار المحلي الخالي من الحلقات في RPL المختلط إلى تقليل التأخير وقيود الذاكرة في معالجة الحلقات أثناء تغير هيكلية الشبكة. خاصة في تطبيقات الزمن الحقيقي، مثل المراقبة الصحية الذكية، حيث لا يمكن قبول التأخير المفرط لأنه قد يؤثر على حياة المريض. في هذه الرسالة، تم استخدام تقنيات التقييم بالمحاكاة باستخدام Cooja Contiki simulator والتحليل الرياضي. حيث يتم التحقق من جدوى تحسين RPL المقترح بشكل تجريبي من خلال تطوير بعض السيناريوهات لوضع RPLغير المختلط (التخزين النقي والتخزين غير النقي) بالإضافة إلى الوضع المختلط RPL بنسب مئوية مختلفة من التخزين وعدم التخزين. مقاييس الأداء التي تم استخدامها هي استهلاك الذاكرة (من حيث إدخالات التوجيه) وإجمالي التأخير من النهاية إلى النهاية ومجموع نفقات التوجيه الإجمالية. استنادا إلى نتائج المحاكاة، يمكن الوصول إلى تقليل استهلاك الذاكرة في الشبكة الهجينة المدمجة بإصلاح الشبكة بدون حلقة التكرار بنسبة 25.22٪ إلى 33.9٪ مقارنة بالشبكات المتجانسة. يساهم المخطط المقترح في أداء أفضل من حيث نسبة تسليم الحزم (PDR) مقارنة بالتخزين المتجانس والشبكة المتجانسة غير المخزنة ولكن مع تأخير أكبر. يمكن أيضًا ملاحظة انخفاض كبير في تكلفة اعادة التوجيه مقارنة بالتخزين المتجانس ونظام عدم التخزين المتجانس بدون آلية إصلاح الشبكة بدون حلقة التكرار. قد لا يظهر التأثير بصورة واضحة شبكة صغيرة الحجم. ولكن مع نمو الشبكة يمكن الوصول إلى تحسن بنسبة قد تصل إلى 33.9٪.بالإضافة إلى نهج المحاكاة، تم النظر في التحليل الرياضي لقياس مقاييس

الأداء مثل استهلاك الذاكرة (بالبايت)، والتأخير الكلي من النهاية إلى النهاية وتوجيه اكتشاف المسار.

APPROVAL PAGE

The thesis of Wan Fariza Wan Abdul Rahman has been approved by the following:

Aisha Hassan Abdalla Hashim
Supervisor

Md. Rafiqul Islam
Co-Supervisor

Othman Omran Khalifa
Internal Examiner

Ali Chekima
External Examiner

Nor Kamariah Noordin
External Examiner

Akram Zeki Khedher
Chairman

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Signature …………………………… Date……23rd August 2021……

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Signature Date

This thesis is dedicated to my late parents for laying the foundation of what I turned out to be in life.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

6LoWPAN	IPv6 over Low Power WPAN
ABRO	Authoritative Border Router Option
ACK	Acknowledgement
AID	Adaptation Identifier
ARM	Available Routing Memory
ARO	Address Registration Option
CoRE	Constrained RESTful Environments
CPU	Central Processing Unit
CTS	Clear to Send
DAD	Duplicate Address Detection
DAG	Directed Acyclic Graph
DAO	Destination Advertisement Object
DAO-ACK	Destination Advertisement Acknowledgement
DHCPv6	Dynamic Host Configuration Protocol version 6
DIO	DODAG Information Object
DIS	DODAG Information Solicitation
DODAG	Destination Oriented Acyclic Graph
DODAGID	DODAG Identification
DRP	DODAG Repair Reply
DRPID	128-bit IPv6 address of the node that is destination of the DRP message
DRQ	DODAG Repair Request
DRQID	128-bit IPv6 address of the node generating the DRQ message
DRSN	DRQ Sequence Number
DTSN	Destination Advertisement Trigger Sequence Number
ETX	Expected Transmission Count

EUI	Extended Unique Identifier
FCS	Frame Check Sequence
HC	Hop Count
H-RPL	Hierarchical RPL
HRLFR	Hybrid RPL with Loop-Free Repair
HTTP	Hypertext Transfer Protocol
ICMPv6	Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IoT	Internet-of-Things
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
LLN	Low-Power and Lossy Networks
MAC	Media Access Control
MFR	MAC Footer
MH	Maximum Number of Hops
MHR	MAC Header
MHRI	Min Hop Rank Increase
MOP	Mode of Operation
MPDU	MAC Protocol Data Unit
MP2P	Multipoint-to-point
MRI	Max Rank Increase
MTU	Maximum Transfer Unit
N-DAO	Non-Storing DAO
ND	Neighbour Discovery
NS	Neighbour Solicitation
NUD	Neighbour Unreachable Detection
OCP	Objective Code Point
OF	Objective Function
OUI	Organizational Unique Identifier

P	Piggybacked Data
P2MP	Point-to-multipoint
P2P	Point-to-point
PAN	Personal Area Network
PCAP	Packet Capture File
PDR	Packet Delivery Ratio
PHY	Physical Layer
PPDU	Physical Protocol Data Unit
PSDU	Physical Service Data Unit
QoS	Quality of Service
RA	Router Advertisement
RankP	Rank of the node transmitting the DRP message
RankQ	Rank of the node generating DRQ message
RC	Required Memory Container
RCL	Route Change Latency
RD	Route Discovery
RFC	Request for Comments
ROLL	Routing over Low Power and Lossy Networks
RPL	IPv6 route-over Routing Protocol for LLNs
RM	Routing Memory
RRM	Required Routing Memory
RTP	Real-time Transport Protocol
RTS	Request to Send
S-DAO	Storing-DAO
SON	Smart Object Network
SRH	Source Routing Header
SYNC	Synchronization
TTL	Time-to-Live
UDGM	Unit Disk Graph Medium
UDP	User Datagram Protocol

LIST OF SYMBOLS

a	Length of simulation area
b	Width of simulation area
B_w	Network bandwidth
C	Counter
C_1	Additional coverage index of a node having 1 node as its neighbours
C_2	Additional coverage index of a node having 2 nodes as its neighbours
C_3	Additional coverage index of a node having 3 nodes as its neighbours
C_4	Additional coverage index of a node having 4 nodes as its neighbours
C_i	Additional coverage index of a node having *i* nodes as its neighbours
C_{DRP}	Routing overhead cost for sending DRP
C_{DRQ}	Routing overhead cost for sending DRQ
C_E	Routing cost
C_{PE}	Child-parent entry
C_{RD}	Total routing overhead cost for route discovery
δ	Time for reassembly and fragmentation at intermediate hops
D_{ID}	DIO interval doubling
D_{IM}	DIO interval minimum

D_{RC}	DIO redundancy constant
$Delay_{e2e}$	Total end-to-end delay for RPL without loop-free repair
$Delay_{e2e\_LFR}$	Total end-to-end delay for RPL with loop-free repair
DL	Default lifetime
DRP_n	The *n*th DRP received
$E[RCL]$	Expected value for RCL
f	Number of fragments
h	Number of hops
h_{DRP}	h_i which generates the DRP message
h_i	Any hop
h_{max_limit}	Hop up to maximum TTL limit
H	Expected number of hops in the network
HD_{ID}	DODAG ID
HD_{VN}	DODAG version number
HR_{ID}	RPL instance ID
I	Current interval size
KHN_E	K-hop neighbour entry
L_{ACK}	Size of ACK packet
L_{ctl}	Size of the control packet
L_{CTS}	Size of the CTS packet
L_{data}	Size of the data packet
L_{hdr}	Header size of the data packet
L_{RTS}	Size of the RTS packet
LU	Lifetime unit
m	Number of failure(s) in transmission

M_L	Required leaf memory
M_M	Additional multicast memory
M_{MSR}	RRM for a multicast Storing router
M_{NR}	RRM for a Non-Storing router
M_{SR}	Routing memory for a multicast Storing router
M_{UR}	RRM for an upward router
max_retrans	Maximum retransmission allowed
$MAX_{UNICAST\_SOLICIT}$	Maximum unicast solicitation
MC_{hybrid}	Memory consumption for hybrid RPL
$MC_{non-storing}$	Memory consumption for homogeneous Non-Storing
$MC_{storing}$	Memory consumption for homogeneous Storing
n	Total number of nodes in the network
n_{DRP}	Number of entries in child-parent table
N_C	Number of entries in child-parent table
N_{HS}	Number of hops to the source of the undeliverable packet
N_i	Number of neighbours in the tier *i* that are in connection with the next tier
N_j	Expected number of neighbours at *j*th hop
N_K	K-Hop neighbours
N_{LH}	Last known hop count to the destination
N_{MOP}	MOP of the node
$N_{non-storing}$	Number of Non-Storing nodes
N_{OCP}	Number of OCPs
N_P	Number of parents

N_R	Number of entries in routing table
N_{RC}	Number of RM containers
$N_{storing}$	Number of Storing nodes
$O2M_{MAP}$	One to many mappings between each OF and the corresponding RMs
OCP	Objective code point
OL	Other required memory by the leaf
OMS	Other required memory by a multicast Storing router
ON	Other required memory by a Non-Storing router
OS	Other required memory by a Storing router
OU	Other required memory by an upward router
p	Probability that an arbitrary node X is located in the wireless transmission range of node S
π	Ratio of the circumference of a circle to its diameter
P_{DTSN}	Additional routing memory to maintain the destination advertisement trigger sequence number (DTSN)
P_{ID}	Parent ID
P_{MOP}	Parent MOP
Q_D	Queue to buffer downward relay packets
Q_U	Queue to buffer upward relay packets
r	Wireless range
R_E	Route entry
R_{max}	Maximum ring size
R_{MSR}	RRM for multicast Storing router
R_N	Own rank
R_P	Parent rank

RC	RM container
$RETRANS_{TIMER}$	Minimum timeout for retransmission
τ_1	Constant time initially used for non-propagating DRQ
τ_2	Node traversal time
T	Time
$T_{lifetime}$	Lifetime of node
T_{np}	Intermediate nodes' processing time
T_{NUD}	Time required to detect router unreachability
T_p	Propagation delay
T_{RD}	Time consumed for route discovery
T_{ro}	Total transmission delay for route-over routing
T_{tran}	Minimum packet transmission time
T_w	Waiting time at contention period
$TTL(h_{DRP})$	Hop h_i at which the DRP is generated