DETERMINING ZONE RADIUS OF ZONE ROUTING PROTOCOL BY EMPLOYING RECURRENT NEURAL NETWORK IN THE 5G WIRELESS NETWORK

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DOCTOR OF PHILOSOPHY
(ELECTRICAL AND ELECTRONIC ENGINEERING)

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ABSTRACT

In addressing the imperatives of 5G wireless networks, the development of network infrastructure capable of accommodating connectivity demands across diverse innovative technologies while upholding high-quality network standards becomes utmost important. In this quest, the selection of an appropriate network architecture, given the need to foster dynamic, self-organizing networks. This study employs a wireless mesh network (WMN) as the foundational network infrastructure due to its adaptability in evolving environmental conditions. Furthermore, the incorporation of unlicensed spectrum harmonious with 5G New Radio, as outlined in 3GPP Release 16, is enacted. In the quest to formulate an efficacious routing protocol capable of exercising traffic control in the face of escalated mobile data utilization, it is essential to ensure Quality of Service (QoS) for end users while optimizing resource efficiency. The Zone Routing Protocol (ZRP) is adopted to cater to the multifarious challenges encountered by WMNs, encompassing the constant flux of network topology, power transmission intricacies, and asymmetrical connections. Notably, the efficacy of ZRP is intertwined with the zone radius parameter, necessitating a dependable approach to its determination. In Addressing this, the proposed approach introduces the long short-term memory recurrent neural network (LSTM-RNN) algorithm. This algorithm empowers ZRP to dynamically adjust the zone radius value in accordance with network performance metrics routing overhead, energy consumption, throughput, and user usage. A dataset comprising these input metrics is partitioned into training and testing subsets, aiding the algorithm in predicting the optimal zone radius value. The efficacy of this methodology is scrutinized in both static and mobile node environments. In terms of network capacity, a bandwidth of 300 Mbps, aligning with the requisites of 5G wireless network technology, is employed. The comparative evaluation of the proposed LSTM-RNN ZRP against conventional ZRP is conducted on the basis of network performance and performance measurement. The zone radius values derived for static nodes fall within the range of 2-6 for the proposed approach and 2-7 for conventional ZRP. Similarly, for both static and mobile node environments, the range of zone radius values spans 1-7 for both algorithms. Analysing the algorithm's performance metrics, including mean square error, error histogram, regression values, and time series response, affirms its effectiveness. Moreover, the network performance evaluation showcases distinctive trends. Notably, LSTM-RNN ZRP demonstrates enhanced throughput and diminished routing overhead and energy consumption compared to conventional ZRP, underlining its efficiency. The number of users reached by nodes is also higher with LSTM-RNN ZRP, elucidating its superiority in user engagement. The novelty of this research lies in the algorithm's operation within an unlicensed spectrum with a bandwidth capacity of 300 Mbps, congruent with the parameters of 5G New Radio in 3GPP Release 16.

ABSTRAK

Untuk menangani keperluan rangkaian tanpa wayar 5G, pembangunan infrastruktur rangkaian yang mampu menampung permintaan ketersambungan merentasi pelbagai teknologi inovatif sambil mengekalkan standard rangkaian yang berkualiti tinggi menjadi penting. Dalam usaha ini, pemilihan senibina rangkaian yang sesuai, dengan mengambil kira keperluan untuk menggalakkan rangkaian yang bersifat dinamik dan mampu mengatur diri, adalah sangat kritikal. Kajian ini menggunakan rangkaian jaringan wayarles (WMN) sebagai infrastruktur rangkaian asas kerana kebolehsuaiannya terhadap keadaan persekitaran yang berubah-ubah. Tambahan pula, penggabungan spektrum tidak berlesen yang harmoni dengan Radio Baharu 5G, seperti yang digariskan dalam Keluaran 3GPP 16, digubal. Dalam usaha untuk merumuskan protokol penghalaan yang berkesan yang mampu melaksanakan kawalan trafik dalam menghadapi peningkatan penggunaan data mudah alih, adalah penting untuk memastikan Kualiti Perkhidmatan (QoS) untuk pengguna akhir sambil mengoptimumkan kecekapan sumber. Protokol Penghalaan Zon (ZRP) diguna pakai untuk menampung pelbagai cabaran yang dihadapi oleh WMN, merangkumi fluks berterusan topologi rangkaian, selok-belok penghantaran kuasa dan sambungan tidak simetri. Terutama sekali, keberkesanan ZRP berkait rapat dengan parameter jejari zon, yang memerlukan pendekatan yang boleh dipercayai untuk penentuannya. Untuk menangani perkara ini, pendekatan yang dicadangkan memperkenalkan algoritma rangkaian saraf berulang jangka pendek (LSTM-RNN) memori jangka pendek. Algoritma ini memperkasakan ZRP untuk melaraskan nilai jejari zon secara dinamik mengikut metrik prestasi rangkaian—overhed penghalaan, penggunaan tenaga, pemprosesan dan penglibatan pengguna. Set data yang terdiri

daripada metrik input ini dibahagikan kepada subset latihan dan ujian, membantu algoritma dalam meramalkan nilai jejari zon optimum. Keberkesanan metodologi ini diteliti dalam kedua-dua persekitaran nod statik dan mudah alih. Dari segi kapasiti rangkaian, lebar jalur 300 Mbps, sejajar dengan keperluan teknologi rangkaian wayarles 5G, digunakan. Penilaian perbandingan LSTM-RNN ZRP yang dicadangkan terhadap ZRP konvensional dijalankan berdasarkan prestasi rangkaian dan pengukuran prestasi. Nilai jejari zon yang diperolehi untuk nod statik berada dalam julat 2-6 untuk pendekatan yang dicadangkan dan 2-7 untuk ZRP konvensional. Begitu juga, untuk kedua-dua persekitaran nod statik dan mudah alih, julat nilai jejari zon menjangkau 1-7 untuk kedua-dua algoritma. Menganalisis metrik prestasi algoritma, termasuk ralat min kuasa dua, histogram ralat, nilai regresi dan tindak balas siri masa, mengesahkan keberkesanannya. Selain itu, penilaian prestasi rangkaian mempamerkan trend tersendiri. Terutama sekali, LSTM-RNN ZRP menunjukkan daya pemprosesan yang dipertingkatkan dan overhed penghalaan yang berkurangan serta penggunaan tenaga berbanding ZRP konvensional, menggariskan kecekapannya. Bilangan pengguna yang dicapai oleh nod juga lebih tinggi dengan LSTM-RNN ZRP, menjelaskan keunggulannya dalam penglibatan pengguna. Kebaharuan penyelidikan ini terletak pada operasi algoritma dalam spektrum tidak berlesen dengan kapasiti lebar jalur 300 Mbps, selaras dengan parameter Radio Baharu 5G dalam Keluaran 3GPP 16.

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APPROVAL

The Examination Committee has met on **9th Mei 2023** to conduct the final examination of **Fadli Sirait** on his degree thesis entitled **"Determining Zone Radius of Zone Routing Protocol by Employing Recurrent Neural Network in the 5G Wireless Network".**

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LIST OF ABBREVIATIONS

eMBB	-	enhanced Mobile Broadband
URLLC	-	Ultra-Reliable Low-Latency
mMTC	-	massive Machine-To-Machine
ITU-R	-	International Telecommunication Union Radio Communication sector
5G	-	the Fifth Generation of Wireless Communications
WMN	-	Wireless Mesh Network
MANET	-	Mobile Ad-hoc Network
ZRP	-	Zone Routing Protocol
PDR	-	Packet Delivery Ratio
LSTM-RNN	-	Long Short-Term Memory Recurrent Neural Network
GTU	-	Gated Recurrent Unit
LQ	-	Link Quality
WCNs	-	Wireless Community Networks
CNNs	-	Convolutional Neural Networks
DL	-	Deep Learning
AI	-	Artificial Intelligent
QoS	-	Quality of Service
VDTN	-	Vehicular Delay Tolerant Network
DLR+	-	Deep Learning-Based Router
DRL	-	Deep Reinforcement Learning
MDE	-	Mobility, Density, and Energy-Based
ZRP	-	Zone Routing Protocol
NR	-	New Radio
MIMO	-	Multiple-Input Multiple-Output
IMT	-	International Mobile Telecommunication
3GPP	-	*3rd Generation Partnership Project*
mMTC	-	massive Machine Type Communications

D2D	-	Device-to-Device
IoT	-	Internet of Things
LTE	-	Long Term Evolution
URLLC	-	Ultra-Reliable Low Latency
VANET	-	Vehicular ad-hoc Network
IEEE	-	Institute of Electrical and Electronics Engineers
DSDV	-	destination sequenced distance vector
OLSR	-	Optimized Link State Routing
HSR	-	Hierarchical State Routing
AODV	-	On-demand Distance Vector
IARP	-	Intra-Zone Routing Protocol
IERP	-	Inter-Zone Routing Protocol
NDP	-	Neighbour Discovery Protocol
ICMP	-	*Internet Control Message Protocol*
BRP	-	Border-cast Resolution Protocol
IP	-	Internet Protocol
ML	-	Machine learning
SVM	-	Support Vector Machines
ECLAT	-	Equivalence Class Transformation
ANN	-	Artificial Neural Network
DNN	-	Deep Neural Networks
CNN	-	Convolutional Neural Networks
ReLUs	-	Rectified Linear Units
CS	-	Core Switch
AP	-	Access Point
RO	-	Routing Overhead
EC	-	Energy Consumption
TH	-	Throughput
UU	-	User Usage
TC	-	Topology Control
MSE	-	Minimum Square Error

LIST OF SYMBOLS

x_i	-	Input Vector
y_i	-	Output Vector
w_i	-	Weighted Input
b	-	Bias
$f(x)$	-	Activation Function
$S(x)$	-	Sigmoid Function
E	-	Error Function (Loss Function)
$\tanh(x)$	-	Hyperbolic tanh
λ	-	Network Function

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CHAPTER 1

INTRODUCTION

1.1 Background

Wireless communication infrastructures have helped several data-hungry applications such as multimedia, online gaming, and streaming high-definition video (Alsharif et al., 2020). Scientists are working to develop a new generation of wireless technology in response to the issue of data-hungry communication systems. At the time of the writing of this report, the 5G communications system as a new generation of mobile communication technology is being deployed all over the world, and it includes features such as enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine-to-machine interactions (mMTC) (ITU-R, 2015). As a new generation of mobile communication technology, more advanced technological solutions are necessary to accomplish faster data rates, lower latency, more capacity, and more efficient spectrum utilization than previous generations (Lin et al., 2019). Moreover, it is noteworthy that 3GPP Release 16 has delineated the specifications for 5G New Radio (5G NR), a significant aspect of which pertains to the potential utilization of unlicensed spectrum resources. A fundamental objective of 5G NR is to afford mobile network operators an expanded spectrum landscape, thereby enhancing their choices for the deployment of 5G network technology.

In this study, it is imperative to delineate that the network infrastructure being examined assumes the configuration of a Wireless Mesh Network (WMN). The primary objective of implementing a Wireless Mesh Network (WMN) is to provide a resilient and high-capacity method of network access to a large user population. This entails creating a reliable and efficient network infrastructure capable of serving a significant number of users while maintaining robust connectivity. (Chaitany et al., 2018). The mesh network architecture entails three essential components, namely, network gateways, access points represented by mesh routers, and the mobile nodes functioning as mesh clients. Within the domain of WMN, various salient attributes come to the fore, encompassing the shared nature of the wireless communication medium, the coexistence of both static and mobile nodes, and the intricate mesh of diverse pathways linking source and destination nodes. It is noteworthy that these inherent characteristics introduce a formidable complexity in the realm of traffic management, particularly within the context of a 5G wireless system, owing to the escalating proliferation of nodes generating substantial volumes of data (Hemalatha & Mercy Shalinie, 2019). Consequently, the imperatives for the effective control of network traffic, as exemplified by the formulation of adept routing algorithms, are progressively assuming heightened significance, driven by the ongoing evolution of wireless networks towards the next generation (Tang et al., 2018).

The procedure of ascertaining the optimal pathways for transmitting data within a network is denoted as routing (Benni & Manvi, 2017a). In order to deliver a data packet from its source to its destination, there is a need to employ a particular routing algorithm, the protocol, which is defined as the collection of rules (Arya et al., 2022). The routing protocol needs to be equipped to deal with the increasing level of node mobility, which often and unpredictably alters the network architecture. Routing protocols based on route discovery are classified into three categories: proactive, reactive, and hybrid (Joy & Dudhe, 2021). Proactive routing protocols are commonly referred to as table-driven protocols due to their characteristic dissemination of routing information to all nodes within the network. In contrast, reactive protocols fall under the category of tableless routing protocols, primarily because they establish routes solely in response to specific demands, leading to a potentially prolonged route discovery process. In the context of a WMN environment, the decision regarding the adoption of either proactive or reactive routing protocols necessitates a comprehensive evaluation of the network's inherent attributes, traffic dynamics, and the precise requisites imposed by the applications operating within the network infrastructure.

The Zone Routing Protocol (ZRP) is a routing protocol that combines the benefits of proactive and reactive routing by maintaining an up-to-date topological map of a zone centered on each node, and within the zone, routes are available immediately; However, for destinations outside the zone, ZRP uses a route discovery method that takes advantage of the zones' local routing information. The connection establishment time can be reduced by using proactive routing inside a limited zone. The zone radius is the most important element that affects ZRP efficiency; the value of the zone radius determines whether ZRP uses proactive or reactive routing (Beijar, 2002). Determining the appropriate zone radius can increase protocol performance by reducing control traffic.