



**Faculty of Electronics and Computer Engineering**

**ANALYSIS ON THE EFFECT OF FIRST-IN FIRST-OUT QUEUE  
LENGTH RATIO TO THE MULTI-HOP WIRELESS NETWORK  
PERFORMANCE**

**Ho Peng Hou**

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**ANALYSIS ON THE EFFECT OF FIRST-IN FIRST-OUT QUEUE LENGTH  
RATIO TO THE MULTI-HOP WIRELESS NETWORK PERFORMANCE**

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**A thesis submitted  
in fulfilment of the requirements for the degree of Master of Science  
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## DECLARATION

I declare that this thesis entitle “Validate and analyse the effect of various queueing configurations to the multi-hop wireless network performance” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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## APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

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Date : 24/9/2014

## **DEDICATION**

I dedicate my thesis work to my family and friends. A special feeling of gratitude to my loving parents, they always support me and encourage me throughout the process. I also dedicate this thesis to my many friends in my university and MIMOS Berhad for helping me solve my technical problems by giving many suggestions. I will always appreciate all they have done.

## ABSTRACT

A multi-hop wireless network is created by connecting multiple wireless access points as the backhaul of the network to increase the network coverage. The issue of spatial bias, unbalanced network performance of end-to-end throughput and delay occurs when the total offered load of the associated stations exceeds the wireless link capacity. Station associated to the access point more hops away from the gateway will experiences significant amount of delay and lower end-to-end throughput compared to the station fewer hops to the gateway. To demonstrate the issue of spatial bias, a Linux based multi-hop wireless network testbed was constructed with six mesh access points (MAP) and a mesh portal. The MAP consists of two ingress interfaces (one to allow the association of station (local ingress interface) and one to allow other MAP to associate to it (mesh ingress interface)) and one egress interface to associate to another MAP. The wireless link capacity of the constructed testbed is determined by the amount of offered load that is about to congest the network. A non-congested access point has the sum of the arrival rate of both the mesh and local ingress interface not larger than the wireless link capacity. Every packet received by both the ingress interfaces of a non-congested access point will be almost immediately forwarded (packets will stay in the transmit queue awhile due to the processing delay) to the destination. However, packet received by a congested access point will be competing not to be dropped and subsequently enqueued into the transmit queue successfully. A transmit buffer (queue of waiting packets) is commonly allocated to the egress interface to fully utilize the wireless link capacity. The process of enqueueing packets into the transmit buffer is handled by a queueing manager (First-In First-Out is the queueing discipline used by the Linux queueing manager). The equality of local successful transmit probability ( $a_n$ ) and mesh successful transmit probability ( $b_n$ ) in congested MAPs, which is the main root cause of the spatial bias problem, is modelled and validated. The proposed solution for the spatial bias problem is to allocate individual transmit buffer with different successful transmit probability for the two ingress interfaces. The hypothesis, “the ratio between the length of local and mesh ingress interface queue can affect the successful transmit probability of the respective interface” is validated by three queueing configurations, namely L100\_M500, L10\_M50 and L10\_M40 that have queues with different length ratios in congested MAPs. If packet arrival ratio of local over mesh ingress interface is larger than the respective queue length ratio, the mesh ingress interface successful transmit probability will be higher than the local ingress interface successful transmit probability. On the other hand, if packet arrival ratio of local over mesh ingress interface is smaller than (or equal to) the respective queue length ratio, the mesh ingress interface successful transmit probability will be lower than (or equal to) the local ingress interface successful transmit probability. The effect to the end-to-end throughput and delay introduced by the proposed solution is analysed. By controlling the ratio of queue lengths, the spatial bias problem in multi-hop wireless network can be alleviated.



## ABSTRAK

Satu rangkaian wayarles pelbagai-hop dibina dengan menghubungkan titik-titik akses wayarles sebagai backhaul rangkaian untuk meningkatkan liputan rangkaian. Rangkaian ini biasanya membolehkan stesen dihubungi ke rangkaian luar atau Internet melalui gerbang atau portal. Isu berat sebelah ruang, prestasi rangkaian dalam pemprosesan akhir-ke-akhir dan kelewatan yang tidak seimbang berlaku apabila jumlah beban ditawarkan oleh stesen-stesen berhubung melebihi kapasiti pautan wayarles. Stesen yang berhubung dengan titik akses yang lebih hop dari gerbang akan mengalami sejumlah besar kelewatan dan lebih rendah pemprosesan akhir-ke-akhir berbanding dengan stesen kurang hop ke gerbang. Oleh itu, rangkaian kajian Linux wayarles pelbagai-hop dibina dengan enam titik akses jaringan (MAP) dan portal jaringan. MAP ini terdiri daripada dua permukaan masuk (satu untuk menghubungkan stesen tempatan (permukaan masuk tempatan) dan satu untuk dihubungi oleh MAP lain (permukaan masuk jaringan)) dan satu permukaan keluar untuk menghubungkan kepada MAP lain. Kapasiti pautan wayarles ditentukan oleh jumlah beban ditawarkan yang hampir sesak rangkaian. Satu titik akses tanpa sesak mempunyai jumlah kadar ketibaan kedua-dua permukaan masuk jaringan dan tempatan tidak lebih besar daripada kapasiti pautan wayarles. Setiap paket yang diterima oleh kedua-dua permukaan masuk titik akses tanpa sesak akan hampir dihantarkan serta-merta (dengan kelewatan pemprosesan) ke destinasi. Walau bagaimanapun, paket yang diterima oleh titik akses sesak akan bertanding supaya tidak dijatuhkan dan berjaya disusun ke dalam barisan penghantar. Satu penampakan menghantar (barisan paket menunggu) biasanya diperuntukkan kepada permukaan keluar untuk menggunakan sepenuhnya kapasiti pautan wayarles. Proses penyusunan paket ke dalam penampakan menghantar dikendalikan oleh pengurus beratur (dalam Linux adalah Masuk-Dahulu-Keluar-Dahulu). Persamaan antara kebarangkalian berjaya menghantar tempatan ( $a_n$ ) dan kebarangkalian menghantar berjaya jaringan ( $b_n$ ) semasa kesesakan adalah punca utama masalah berat sebelah ruang yang dimodelkan dan disahkan. Penyelesaian yang dicadangkan adalah memperuntukkan penampakan menghantar individu yang berbeza dalam kebarangkalian menghantar berjaya untuk dua permukaan masuk. Hipotesis, "nisbah antara panjang baris gilir permukaan kemasukan tempatan dan jaringan boleh menjejaskan kebarangkalian berjaya menghantar antara permukaan masing-masing" disahkan oleh tiga konfigurasi pengaturan, iaitu L100\_M500, L10\_M50 dan L10\_M40 yang mempunyai barisan gilir dengan nisbah panjang yang berbeza dalam MAP yang sesak. Jika nisbah ketibaan paket antara permukaan kemasukan tempatan ke jaringan adalah lebih besar daripada (lebih kecil daripada, sama dengan) nisbah panjang baris gilir masing-masing, kebarangkalian berjaya menghantar permukaan kemasukan jaringan akan lebih tinggi daripada (lebih rendah daripada atau sama dengan) kebarangkalian menghantar berjaya permukaan kemasukan tempatan. Kesan kepada pemprosesan akhir-ke-akhir dan kelewatan diperkenalkan oleh penyelesaian dianalisis. Dengan mengawal nisbah panjang baris gilir, masalah berat sebelah ruang dalam rangkaian wayarles pelbagai-hop boleh dikurangkan.

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## LIST OF SYMBOLS AND UNIT CONVERSION

|                 |   |
|-----------------|---|
| $\mu_{max}$     | - Wireless link capacity  |
| $\lambda_{M_1}$ | - The arrival rate on mesh network ingress interface                        |
| $\lambda_{L_1}$ | - The arrival rate on local network ingress interface                       |
| $I_U$           | - Gateway Utilization Indicator   |
| $T_i(t)$        | - Throughput of Node $i \in S$  |
| $\lambda_i(t)$  | - Instantaneous Offered Load of Node $i \in S$                              |
| $F_i$           | - The Minimum Guaranteed rate of node $i$                                   |
| $R_i(t)$        | - The Rate Limit of Node $i \in S$  |
| $\alpha$        | - Additive decrease (Section 2.1.1)<br>explanatory variable (Section 2.1.2) |
| $\beta$         | - Multiplicative decrease   |
| $x_i$           | - Normalized Throughput   |
| $p$             | - Dropping probability  |
| $h$             | - Number of hops  |
| $q$             | - Current queue length  |
| $CW_{min}$      | - Minimum contention window size  |
| $\alpha_i$      | - Traffic forwarding capability a node $i$                                  |
| $h_i^{out}$     | - Rate of outgoing traffic  |
| $h_i^{in}$      | - Rate of incoming g traffic  |
| $\alpha^*$      | - Target traffic forwarding capability                                      |
| $T$             | - $CW_{min}$ update period  |

|                     |   |
|---------------------|---|
| $\gamma$            | - Step size   |
| InPackets           | - The number of all the incoming packets for $T$                                      |
| DstPackets          | - The number of outgoing packets whose destination is itself                          |
| OutPackets          | - The number of all the outgoing packets for $T$                                      |
| SrcPackets          | - The number of incoming packets whose source is itself                               |
| $\max_{th}$         | - Upper bound on $CW_{min}$   |
| $\min_{th}$         | - Lower bound on $CW_{min}$   |
| $l$                 | Transmission intensity of a link  |
| $p_l$               | Channel access probability  |
| $\mu_l$             | Holding time (or transmission duration in CSMA)                                       |
| $q_l[t]$            | Queue length in MAC layer   |
| $A_l[t]$            | Amount of incoming packets over each link   |
| $S_l[t]$            | Amount of served packets at a frame over the link                                     |
| $[\cdot]^+$         | $\max(\cdot, 0)$  |
| $b$                 | Positive scaling parameter  |
| $vq_l[t]$           | Virtual queue length in MAC layer   |
| $V$                 | Positive control parameter  |
| $\underline{vq}$    | Virtual queue length lower-bound  |
| $[\cdot]_d^c$       | $\max(d, \min(c, \cdot))$   |
| $\lambda_s$         | - Rate of local client traffic that arrives at all MAPs in deterministic distribution |
| $N$                 | - Number of hops  |
| $\lambda_{M_n}$     | - Arrival rate on mesh ingress interface of $MAP_n$                                   |
| $n$                 | - Hop number  |
| $C$                 | - Largest hop number for the congested MAPs   |
| $\lfloor x \rfloor$ | - Floor function  |
| $\lceil x \rceil$   | - Ceiling function  |



|                |  |
|----------------|--|
| $x y$          | - $y$ is divisible by $x$  |
| $x \nmid y$    | - $y$ is not divisible by $x$  |
| $Q_n$          | - Total queue length in the $MAP_n$ transmission queue   |
| $Q_{Ln}$       | - Individual queue length for local ingress interface accepted packets   |
| $Q_{Mn}$       | - Individual queue length for mesh ingress interface accepted packets  |
| $q_{Ln}$       | - The number of waiting packets in the transmission queue that were received by local ingress interface            |
| $q_{Mn}$       | - The number of waiting packets in the transmission queue that were received by the mesh ingress interface         |
| $\forall x$    | - Every $x$  |
| $\mu_{Mn}$     | - Successful transmit rate to $MAP_{n-1}$ for those packets received by mesh ingress interface in $MAP_n$          |
| $\mu_{Ln}$     | - The successful transmit rate to the $MAP_{n-1}$ for those packets received by local ingress interface in $MAP_n$ |
| $a_n$          | - The successful transmit probability of the local ingress interface accepted packets on $MAP_n$ to $MAP_{n-1}$    |
| $b_n$          | - The successful transmit probability of the mesh ingress interface accepted packets on $MAP_n$ to $MAP_{n-1}$     |
| $\lambda_{n0}$ | - End-to-end throughput  |
| $p_{direct_L}$ | - Number of local ingress interface received packets that are directly transmitted in one second                   |
| $p_{--L}$      | - Number of local ingress interface received packets that are dequeued from the local client queue in one second   |
| $p_{drop_L}$   | - Number of local ingress interface received packets that are dropped from local client queue in one second        |
| $p_{++L}$      | - Number of local ingress interface received packets that are enqueued into local client queue in one second       |
| $p_{direct_M}$ | - Number of mesh ingress interface received packets that are directly transmitted in one second                    |
| $p_{--M}$      | - Number of mesh ingress interface received packets that are dequeued from the local client queue in one second    |
| $p_{drop_M}$   | - Number of mesh ingress interface received packets that are dropped   |

from local client queue in one second

$p_{++M}$

- Number of mesh ingress interface received packets that are enqueued into local client queue in one second

$$1pkt/s = \frac{1 * 1470byte * 8bit/byte}{1024 * 1024} = \frac{735}{65536} Mbps$$

## LIST OF ABBREVIATIONS

|       |   |
|-------|---|
| AC    | Access category                                     |
| APs   | - Access points                                     |
| APU   | - Accelerated Processing Unit                       |
| AQM   | Active queue management                             |
| BEB   | - Binary exponential backoff                        |
| CWA   | - Contention window adaptation                      |
| DCF   | - Distributed coordination function                 |
| DDR3  | - Double Data Rate 3 (memory)                       |
| D-ITG | - Distributed Internet Traffic Generator            |
| EDCA  | Enhanced Distribution Channel Access                |
| EQMMN | Enhanced Queue Management in Multi-Hop Networks     |
| FIFO  | - First-In First-Out                                |
| ICMP  | - Internet Control Message Protocol                 |
| IEEE  | - Institute of Electrical and Electronics Engineers |
| IGW   | Internet Gateway                                    |

|       |   |
|-------|---|
| IP    | - Internet Protocol   |
| IPv4  | - Internet Protocol Version 4                               |
| IPv6  | - Internet Protocol Version 6                               |
| ISP   | - Internet Service Provider                                 |
| LAN   | - Local area network  |
| MAC   | Media Access Control  |
| MAP   | - Mesh access point   |
| MP    | - Mesh point  |
| MPP   | - Mesh portal   |
| NTP   | - Network Time Protocol                                     |
| ntpd  | - NTP daemon  |
| oCSMA | Optimal Carrier Sense Multiple Access                       |
| PCI   | - Peripheral Component Interconnect (personal computer bus) |
| PHY   | Physical layer  |
| QMMN  | - Queue Management in Multi-hop Networks                    |
| QoETX | Queue-based OLSR ETX  |
| QoS   | Quality of Service  |
| RF    | - Radio frequency   |
| RL    | Reinforcement learning                                      |

|          |  |
|----------|--|
| RP-SMA   | - Reversed polarized SMA                   |
| RTT      | - Round-Trip Time                          |
| SDRAM    | - Synchronous Dynamic Random Access Memory |
| SMA      | - Subminiature Version A                   |
| STAs     | - Stations                                 |
| TCP      | Transmission Control Protocol              |
| UDP      | - User Datagram Protocol                   |
| USB      | - Universal Serial Bus                     |
| UTeM     | - Universiti Teknikal Malaysia Melaka      |
| VQ-oCSMA | Virtual queue-based oCSMA                  |
| WMN      | - Wireless Mesh Network                    |
| wRED     | - Weighted random early detection          |



## LIST OF PUBLICATIONS

### Journals:

[1] Peng Hou Ho, Kim Chuan Lim Kae Hsiang Kwong. Validate and Analyse the Effect of Various Queueing Configurations to the Multi-Hop Wireless Network Performance. (Submitted) Journal of Network and Computer Applications. Imprint: ELSEVIER. ISSN: 1084-8045.

### Conference papers:

[1] Peng Hou Ho, Derek William Holtby, Kim Chuan Lim, Kae Hsiang Kwong, David Chieng, Alvin Ting and Su Fong Chien. End-to-End Throughput and Delay Analysis of Wi-Fi Multi-hop Network with Deterministic Offered Load. (Accepted) In: *Proceeding of the IET International Conference on Wireless Communications and Applications, ICWCA 2012*, Kuala Lumpur, Malaysia, 8 - 10 October 2012. IET.

[2] Seyed Dawood Sajjadi Torshizi, Peng Hou Ho, Kae Hsiang Kwong, Fazirulhisyam Hashim, Kok Lim Yau, David Chieng. Design and Evaluation of a Messaging Framework for Bandwidth Allocation among End-Users in Wireless Mesh Networks. (Accepted) In: *Proceeding of the 2013 IET International conference on Information and Communications (IETICT 2013)*, Beijing, China, 27 - 29 April 2013. IET.