A Study of Network Neutrality and Differentiated Services
網絡中立性與差異化服務的研究

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Date: Oct-23-2020

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Outline

- Introduction and Motivation
- Definition, some Key Events and debate of Net Neutrality
- Existing Technology of Differentiated Service
- Differentiated Service in the Last Mile
- A public survey of net neutrality in Hong Kong and result analysis
- Conclusion and Future Work

Introduction

- The Internet has been operated on "FCFS" manner for a long time
- Internet's services at its early stage:
  - Information carrier: Message & Images
  - Limited service: e-mail, (Bulletin Board System) BBS
  - Delay can be tolerated
- Today's Internet:
  - Various service including voice calls, video conferencing, videos (movies, live broadcasting), media rich webpages, Virtual Reality, etc.
  - Delay sensitive
- Users' dissatisfaction -> improve network service

Definition, Key Events, Debates of Net Neutrality

Definition: what is Net Neutrality (NN) ?

- Conceptually introduced by Tim Wu in 2003

- No official definition

- To be simple: "treat all the data equally, without discrimination"

Tim Wu, Professor at Columbia Law School
Image source:
https://www.law.columbia.edu/faculty/timothy-wu

- Established date: June 12, 2015 (Obama's administration)
  Repealed date: June 11, 2018 (Trump's administration)

Iconic Events

- 2004/05, Madison River Communications banned VoIP, was Fined $15,000
- 2005, Comcast throttled P2P file sharing applications
- From 2007 to 2009, AT&T stopped Apple using Skype in their iPhone product
- 2011, MetroPCS blocked all the streaming video services except YouTube
- 2012, AT&T restricted only expensive subscription plan users can use "FaceTime" applications in their iPhone
- 2014, customers complained that Netflix and Hulu did not provide the indicated QoS
- July 2017, end-users accused Verizon Wireless that videos from YouTube and Netflix were played slower than usual

Keep going ……

Net neutrality is important, sub-topic of **DIGITAL DIVIDE**.

Debate: Proponents and opponents

Proponents / Advocates:

- End-users,
- Content Providers,
- Small Startups

Opponent / Objector:

- Big ISPs,
- conventional communication company (Infrastructure owners)

Why NN?

- Development and prosperity attribute to NN
- Big ISPs stifle small startups

Why not NN?

- prioritized services is more efficient
- ISPs will lose the incentive
- Revenue of two-sided market is unbalanced

Policy, Economic and Engineering perspectives of Net Neutrality

Policy perspective

Five terms:

1. Vertical Integration
2. Zero-price
3. Price discrimination
4. Zero-rating
5. Non-discrimination

Zero-rating

- A benefit that an internet service provider may offer to their subscribers, who are able to access certain websites, services or applications without being charged, also called “toll-free”

- Regarded as a sub-topic of net neutrality

- We use Zero-rating as an entry point of our public survey

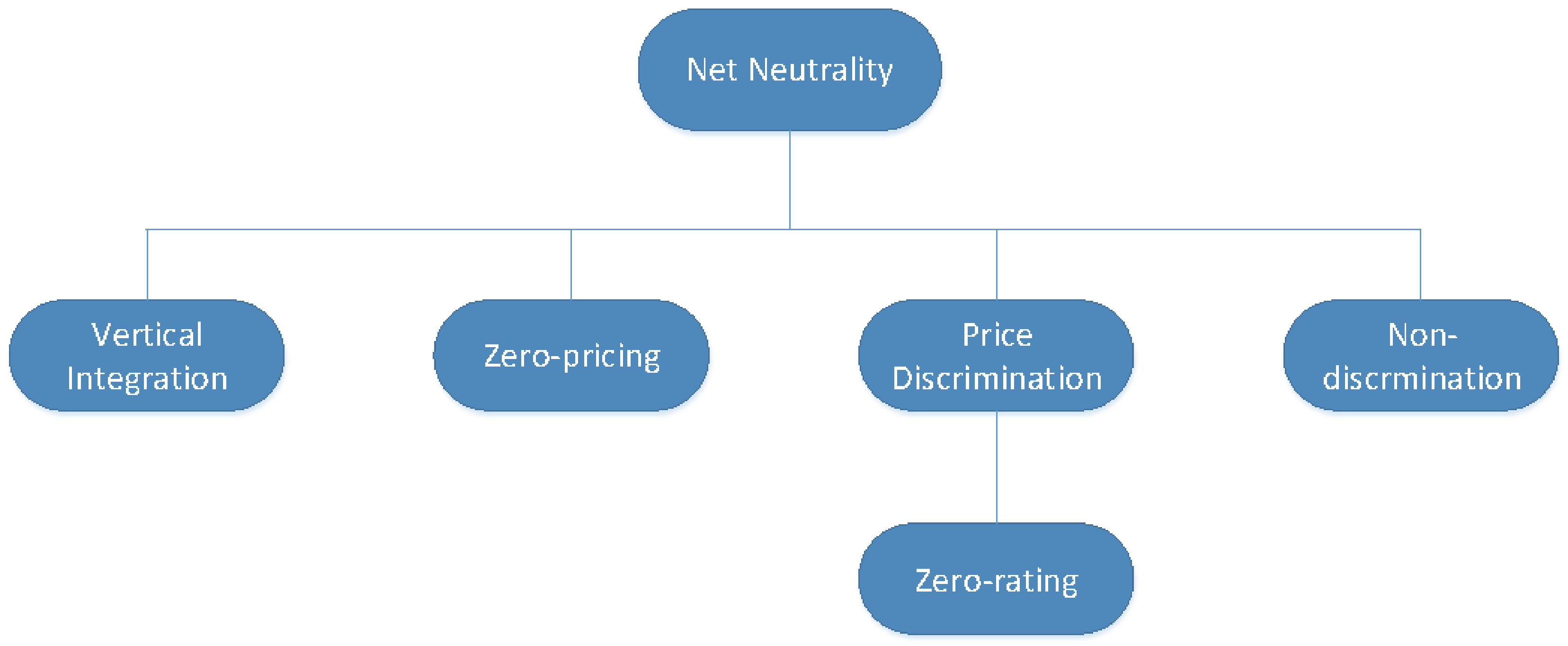
Non-discrimination

- In 2005, “Telecommunication services” was reclassified to “Information services”, where the non-discrimination rule is not compulsory
- Allowing for CPs (e.g., Netflix and Hulu) to pay ISPs (Comcast, Verizon etc.,) extra money to obtain higher priority over other data traffic
- “Non-discrimination” rule is used much frequently in the debate of net neutrality

Summary of policy perspective

NN Proponents: CPs and customers; NN Opponents: ISPs

Certain big ISPs/CPs prefer using zero-rating to subsidize their subscriber, which violate the NN rule.



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Economy Perspective

- Visualized models

- Pricing models:

  Paris Metro Pricing (PMP) Model

  One- and two-sided model

  Other models

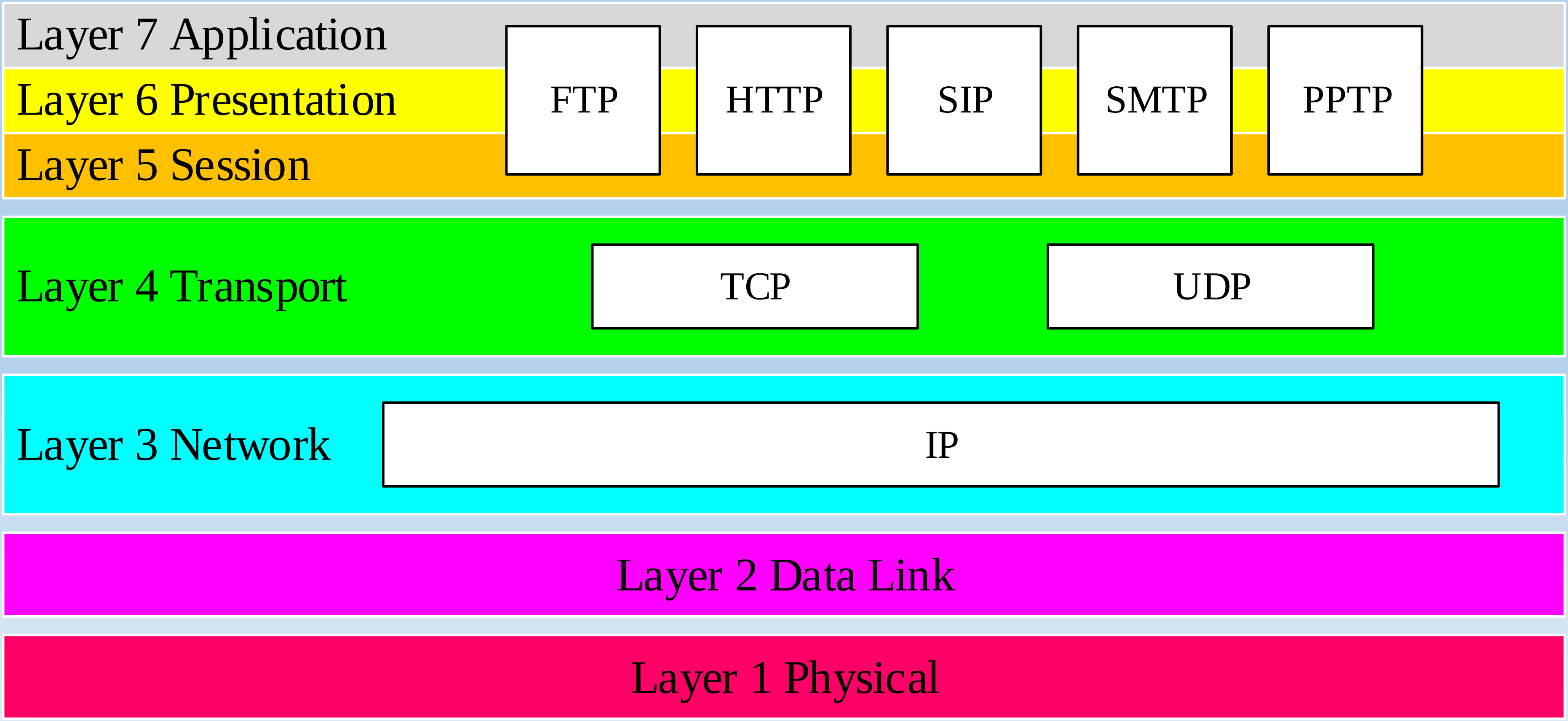
Engineering Perspective

Two analytical tool:

- Game theory
- Queueing theory

Differentiated service in layered structure

Layered structure and protocols therein



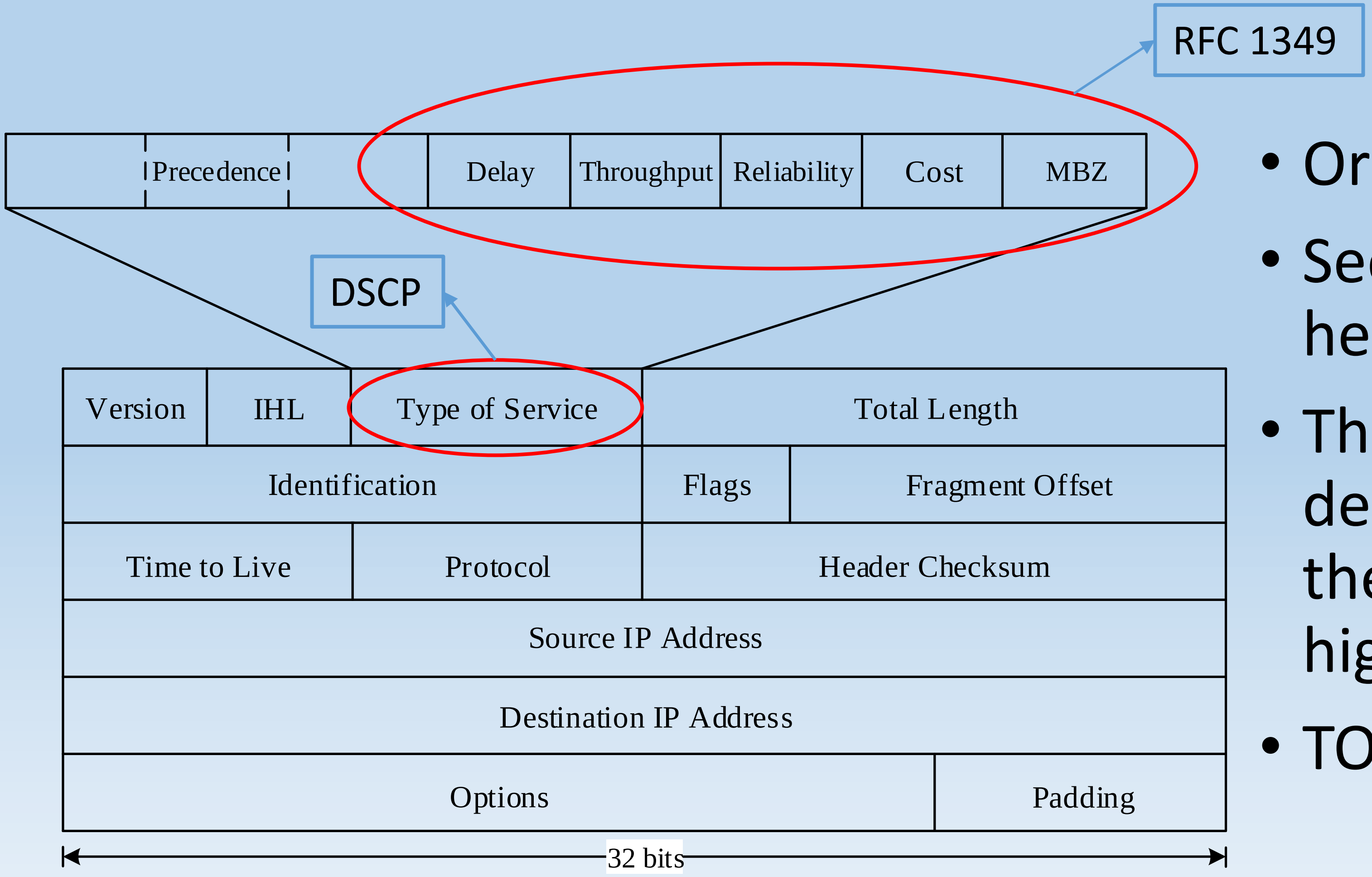
The illustration of OSI 7 Layers model and commonly used protocols

Approaches to implement differentiated service

Existing technologies / architectures:

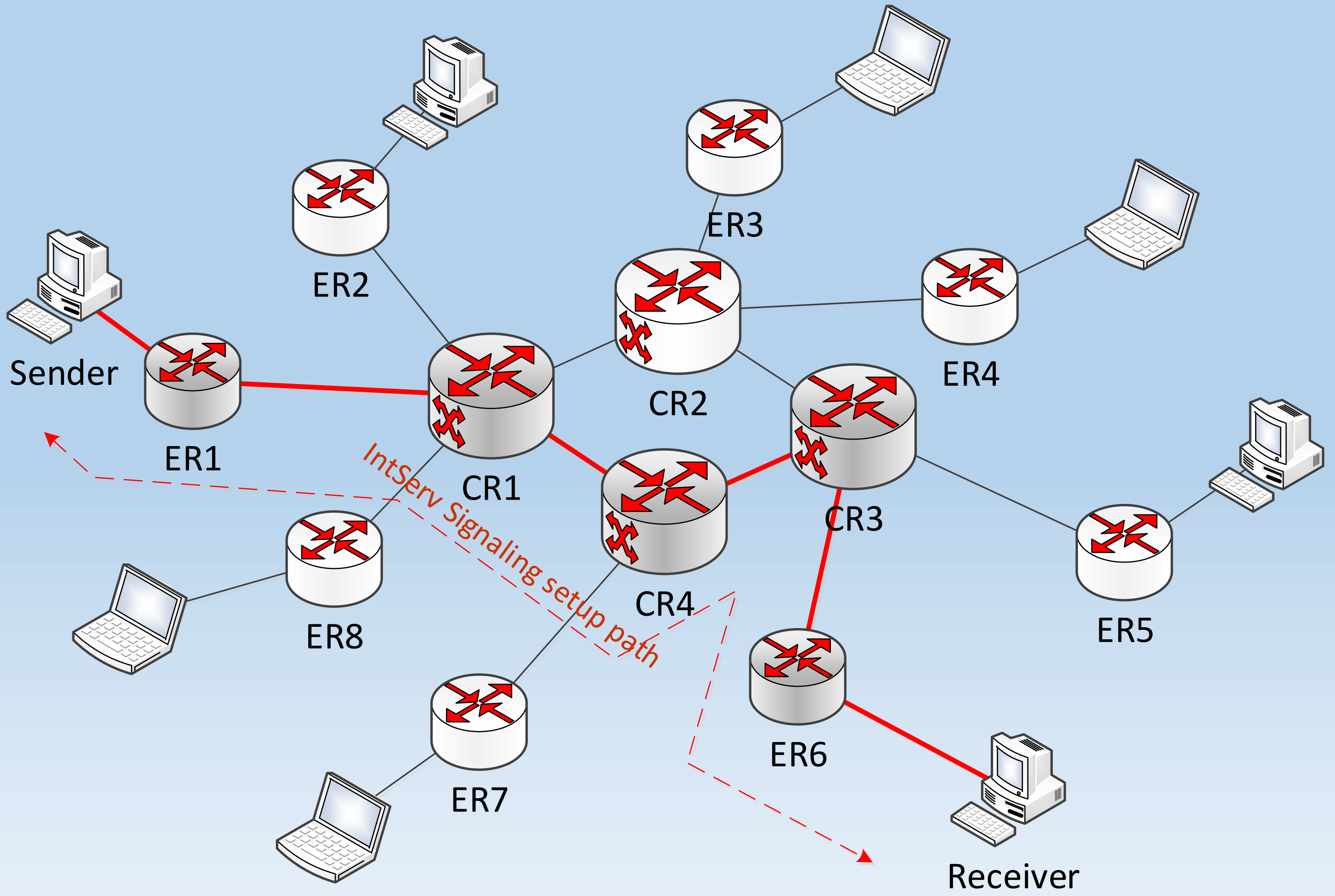
1. IP precedence: Type of Service (TOS)
2. Integrated service (IntServ)
3. Differentiated service (IntServ)

Type of Service (TOS) mechanism



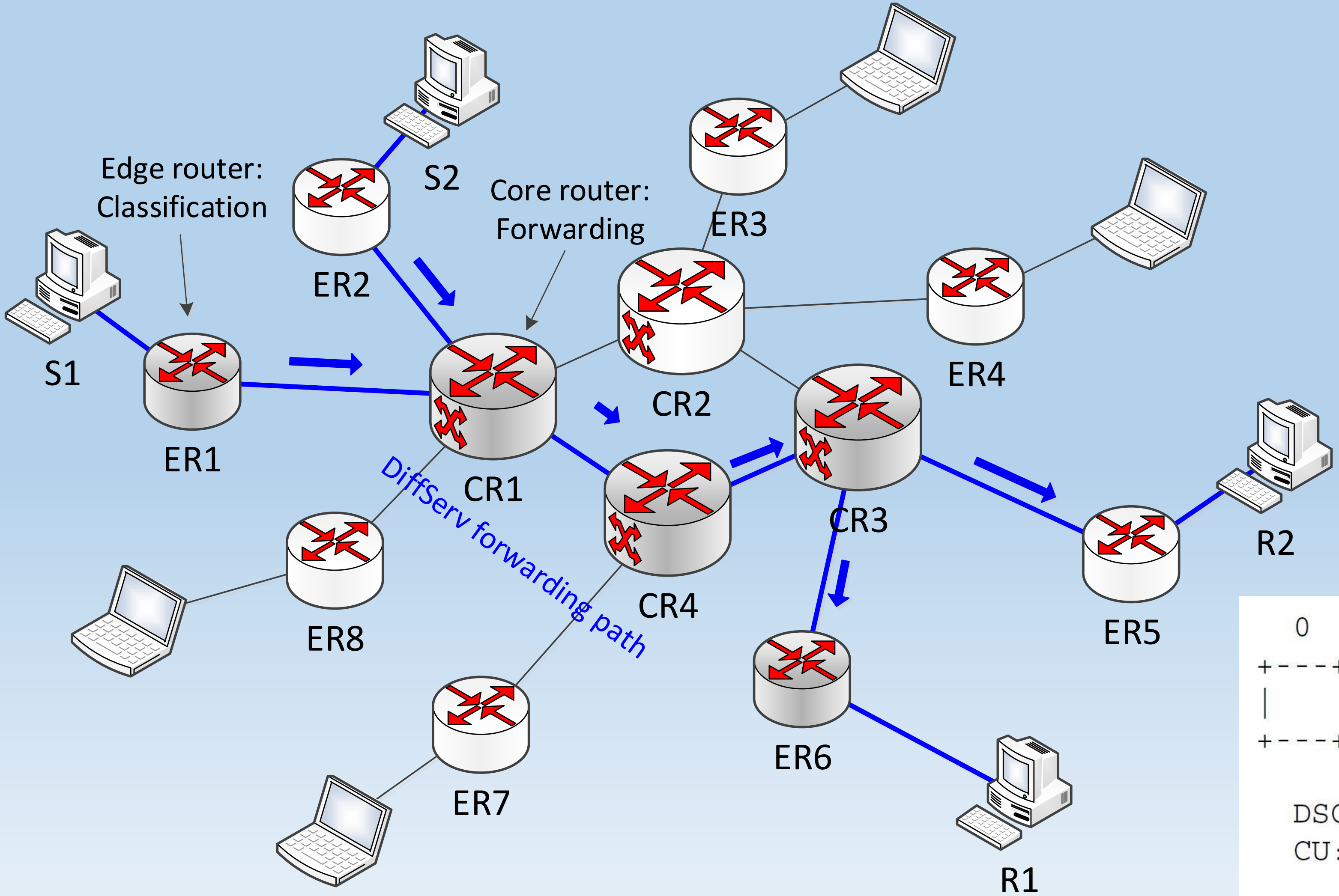
- Originated from RFC 791
- Second byte of the IP header
- The first 3 bits "precedence" decide the priority, '0' gets the lowest and '7' gets the highest
- TOS field -> DSCP in DiffServ

Integrated services (IntServ) architecture:



- RFC 1663 (1994)
- Establish “virtual link”
- Every node compatible
- Fine-grained QoS
- Flow specs:
  - “TSPEC” (Traffic specification)
  - “RSPEC” (Request specification)
- RSVProtocol

Differentiated service (DiffServ) architecture:



- RFC 2474 / 2475 (1998)
- No INFO of each “Flow”
- Per Hop Behavior (PHB)
- DSCP code (previously, TOS field)

```
  0   1   2   3   4   5   6   7
+---+---+---+---+---+---+---+---+
|         DSCP          |  CU   |
+---+---+---+---+---+---+---+---+

  DSCP: differentiated services codepoint
  CU:   currently unused
```

IntServ vs. DiffServ

	Pros	Cons
IntServ	1. Per-flow QoS guaranteed; 2. Suitable for managing flows in small networks;	1. Low scalability; 2. High cost including flow signaling and memory of states; 3. Difficult to operation and maintenance; 4. Support limited traffic classes
DiffServ	1. High scalability; 2. No reservation (protocol) needed; 3. Easy to operation and maintenance; 4. Support multilevel traffic classes;	1. Need to coordinate QoS across different DiffServ areas

Differentiated Service (DS) in Last Mile

- Impact of introducing DS on ISPs
- Impact of introducing DS on End-users
- Comparative experiment based on real datasets

Impact of Introducing DS on ISPs

- Analytical tool: M/M/k/k model
- Traffic Assumptions:

  packet size is 1400 Bytes (11200 bits), average number of packets is 800.

  capacity of each channel is: 10 Gbps = 10^10 bit/s

  Priority 1 takes 40%

  Priority 2 takes 50%

  Priority 3 takes 10%

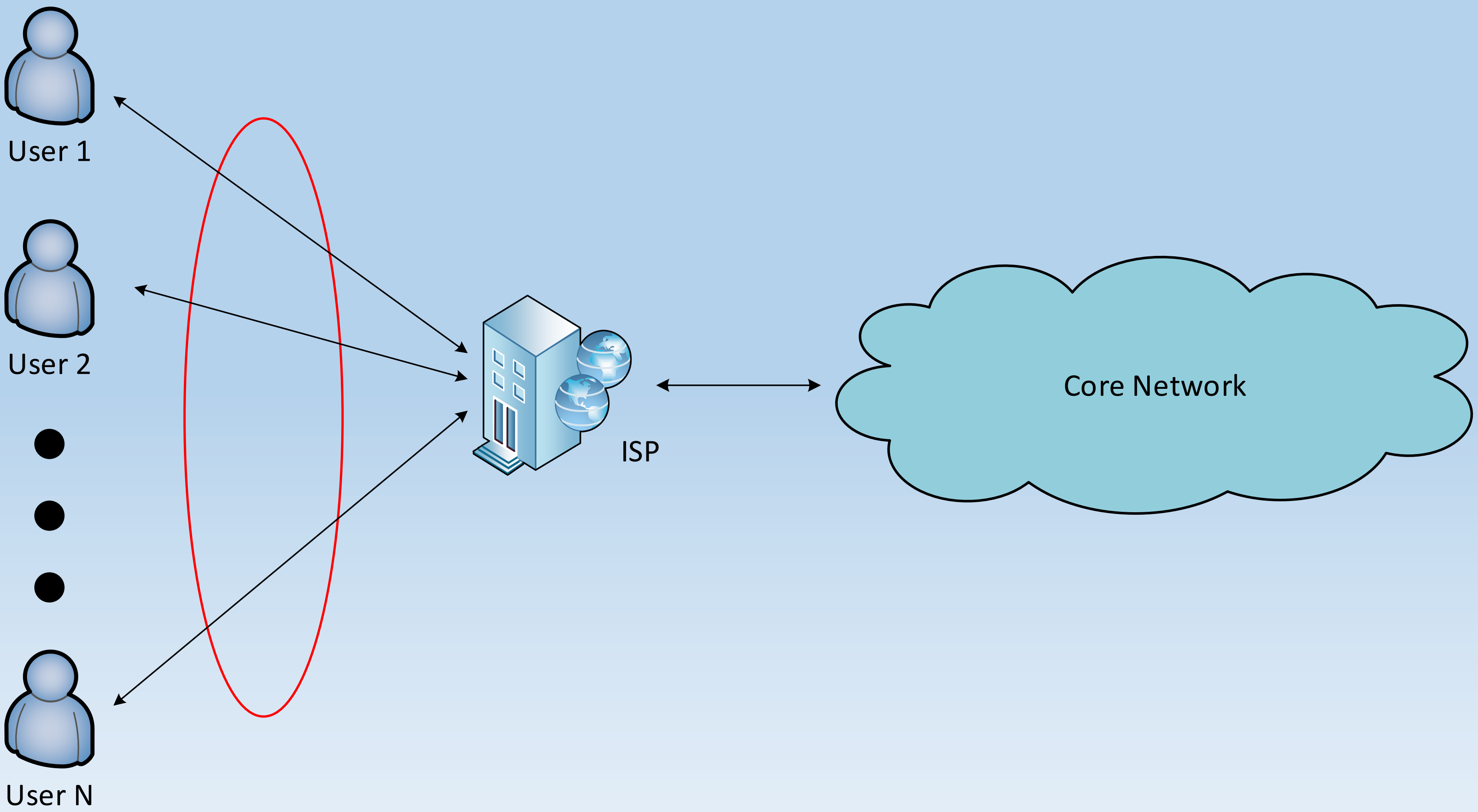
  Then the overall offer load : 4000×1400×8×800/10^10= 3.584 Erlangs. Accordingly,

  Priority 1 provides 1.4336 Erlangs,

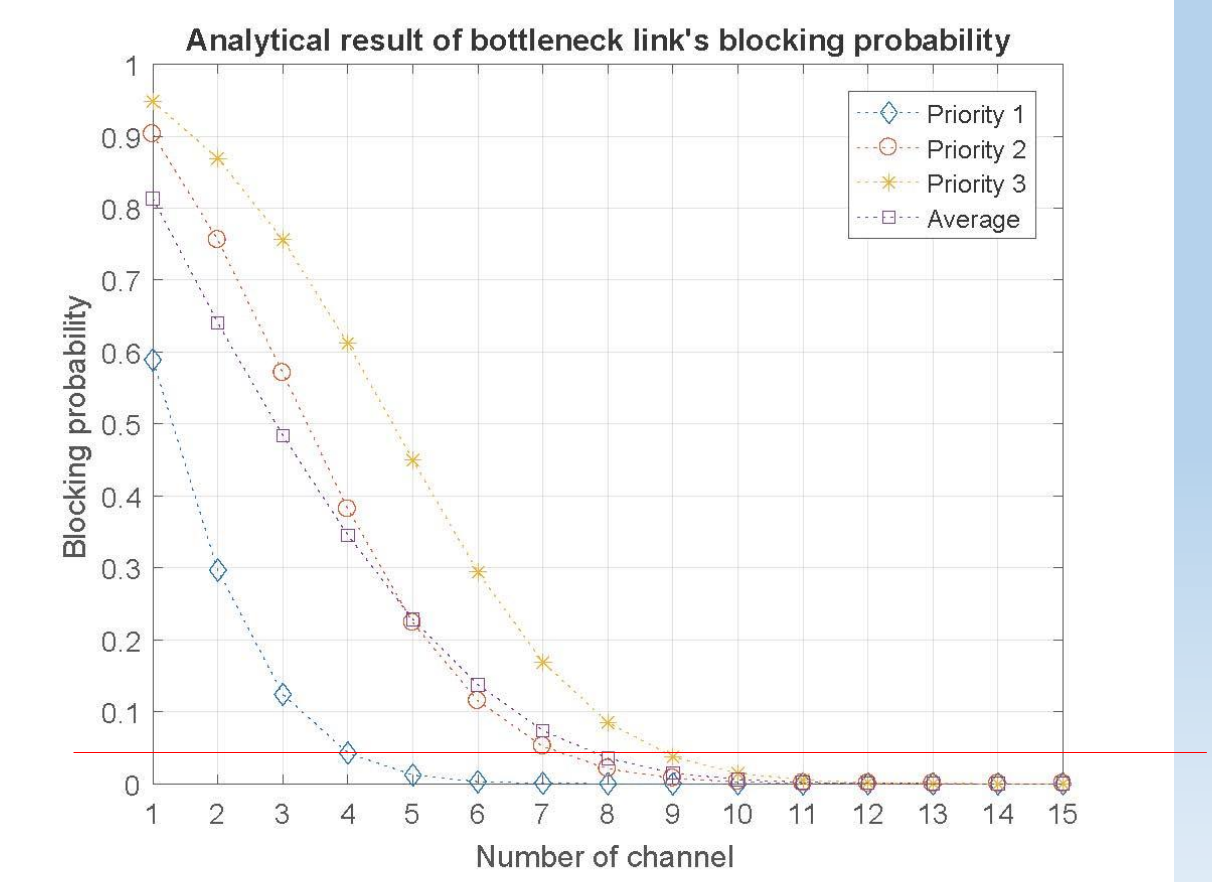
  Priority 2 provides 1.792 Erlangs, and

  Priority 3 provides 0.358 Erlangs.

Wireline network case



Analytical calculation and result



$$B_1 = E(A_1, C),$$

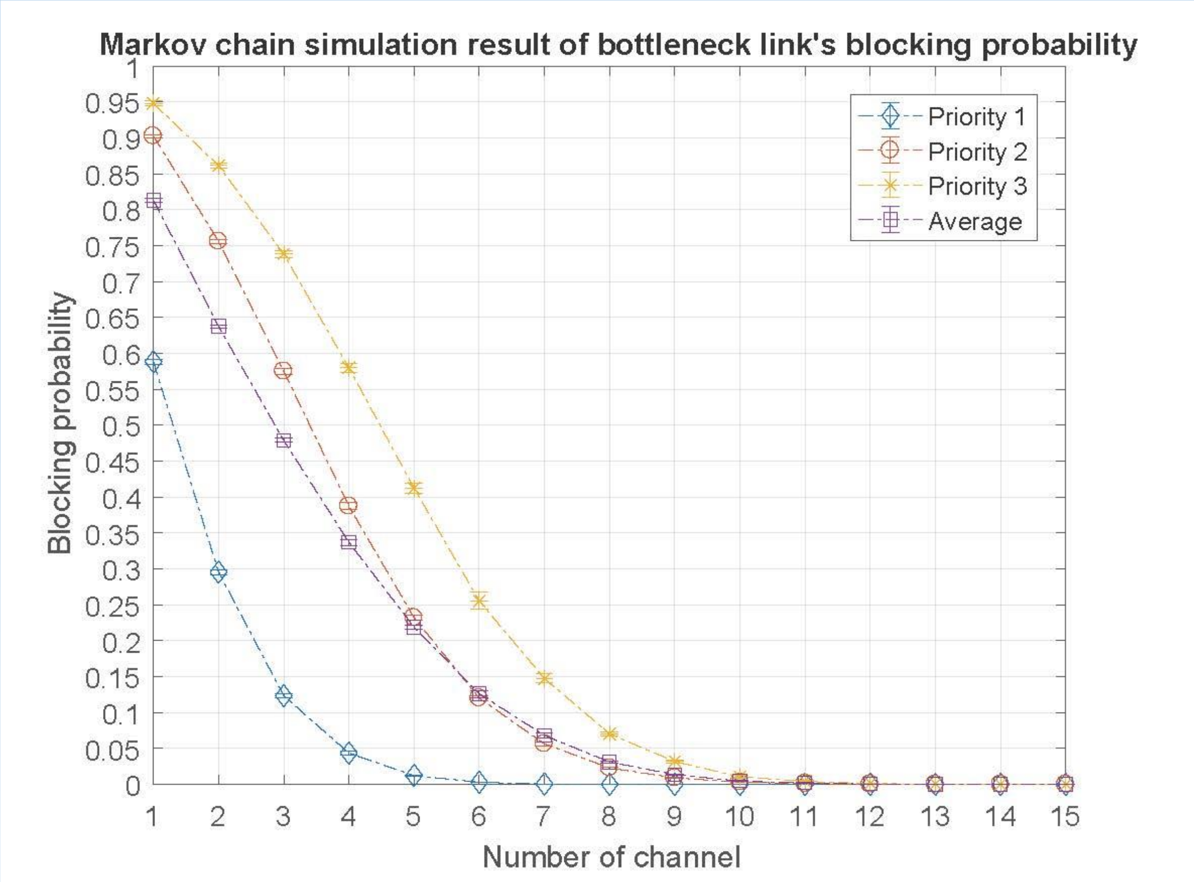
$$B_2 = (E(A_1 + A_2, C) * (A_1 + A_2) - B_1 * A_1)/A_2,$$

$$B_3 = (E(A_1 + A_2 + A_3, C) *$$

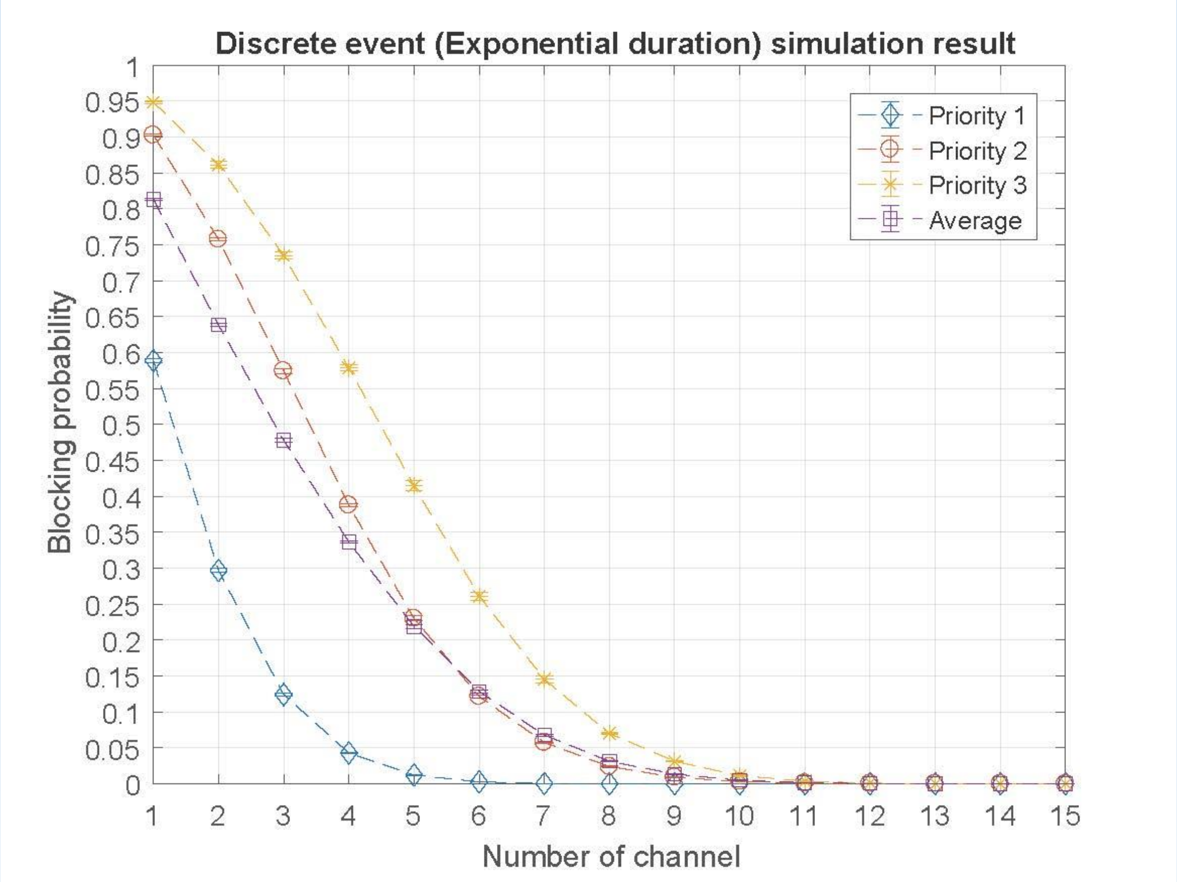
$$(A_1 + A_2 + A_3) - B_1 * A_1 - B_2 * A_2)/A_3$$

Reference point: 5% Bp

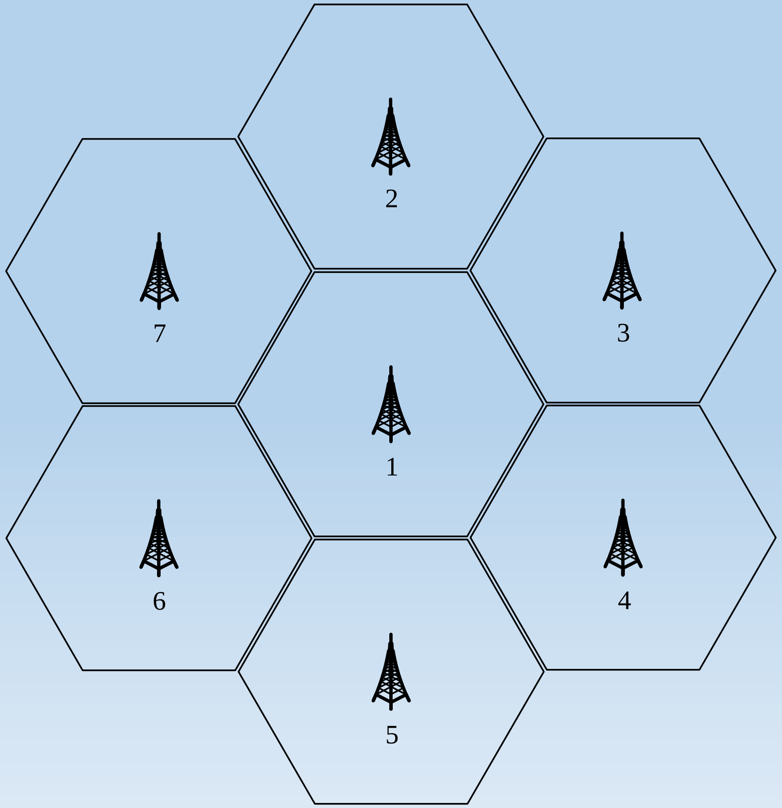
Markov chain simulation result



Discrete event simulation result



Wireless network case (regular)

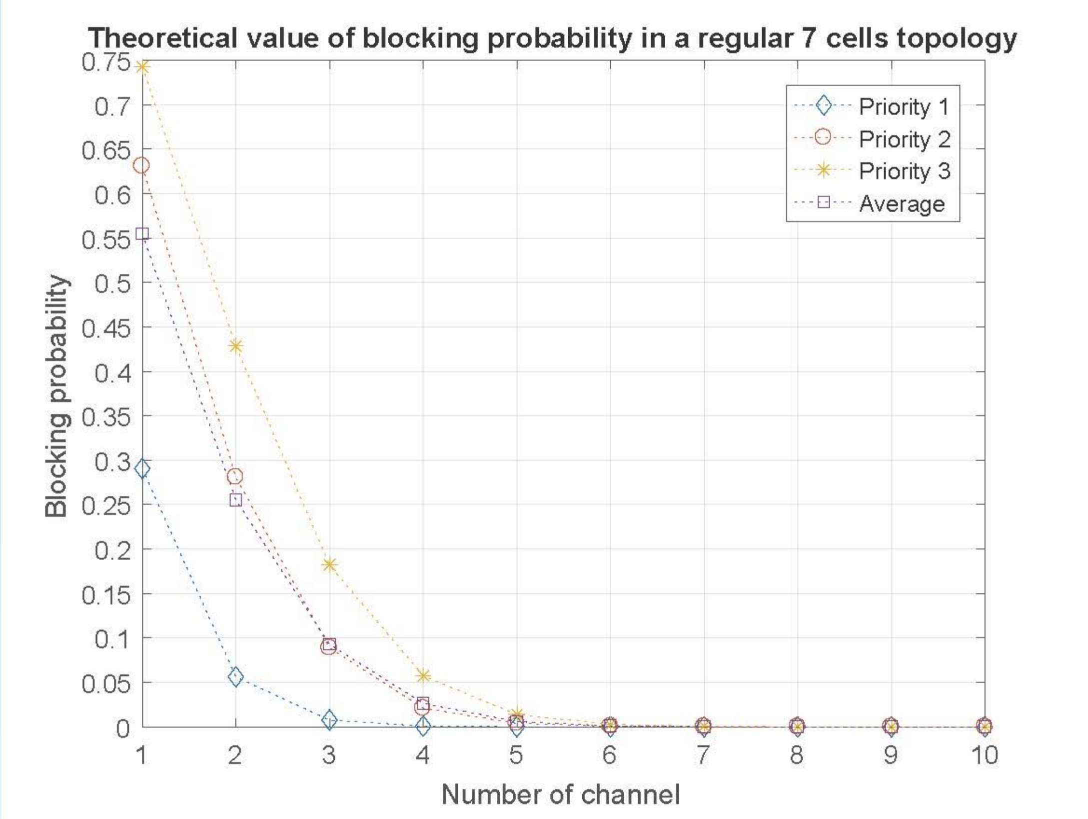


$$P(i,j)_{regular} = \begin{bmatrix} 0 & 1/6 & 1/6 & 1/6 & 1/6 & 1/6 & 1/6 \\ 1/3 & 0 & 1/3 & 0 & 0 & 0 & 1/3 \\ 1/3 & 1/3 & 0 & 1/3 & 0 & 0 & 0 \\ 1/3 & 0 & 1/3 & 0 & 1/3 & 0 & 0 \\ 1/3 & 0 & 0 & 1/3 & 0 & 1/3 & 0 \\ 1/3 & 0 & 0 & 0 & 1/3 & 0 & 1/3 \\ 1/3 & 1/3 & 0 & 0 & 0 & 1/3 & 0 \end{bmatrix}$$

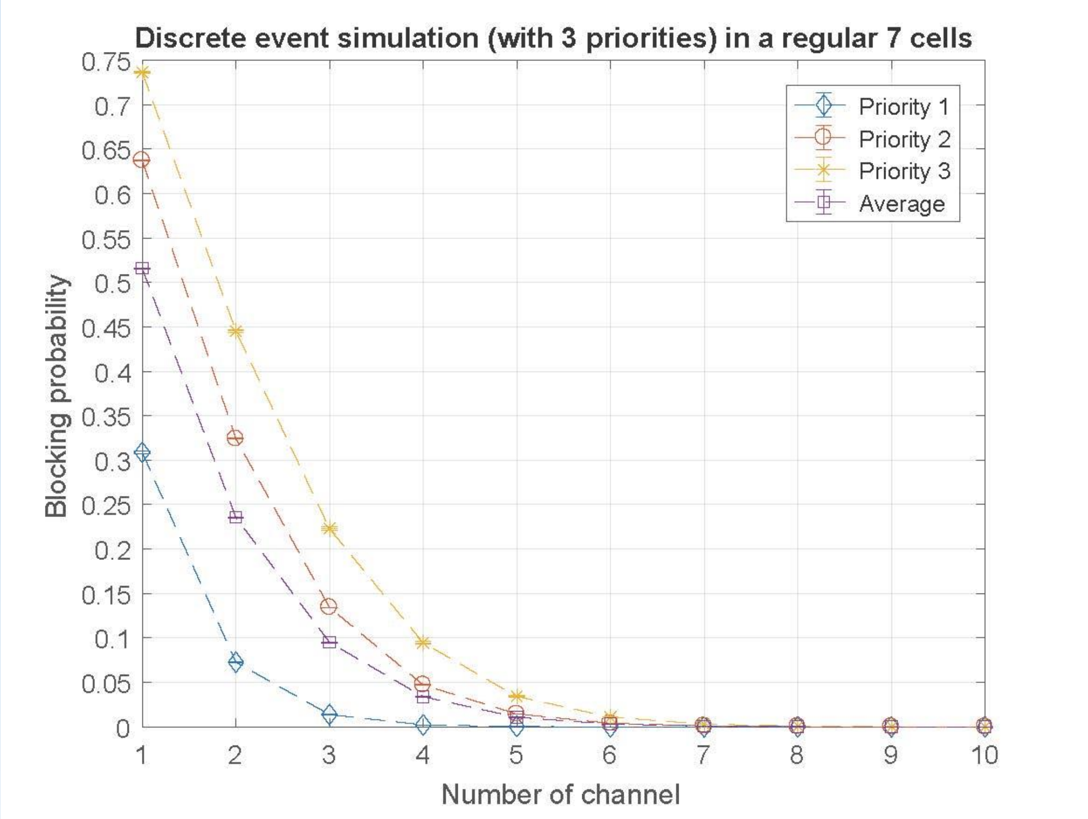
Regular 7 cell topology

Adjacent matrix of handover

Calculation and simulation results (regular)



Theoretical calculation



Simulation result

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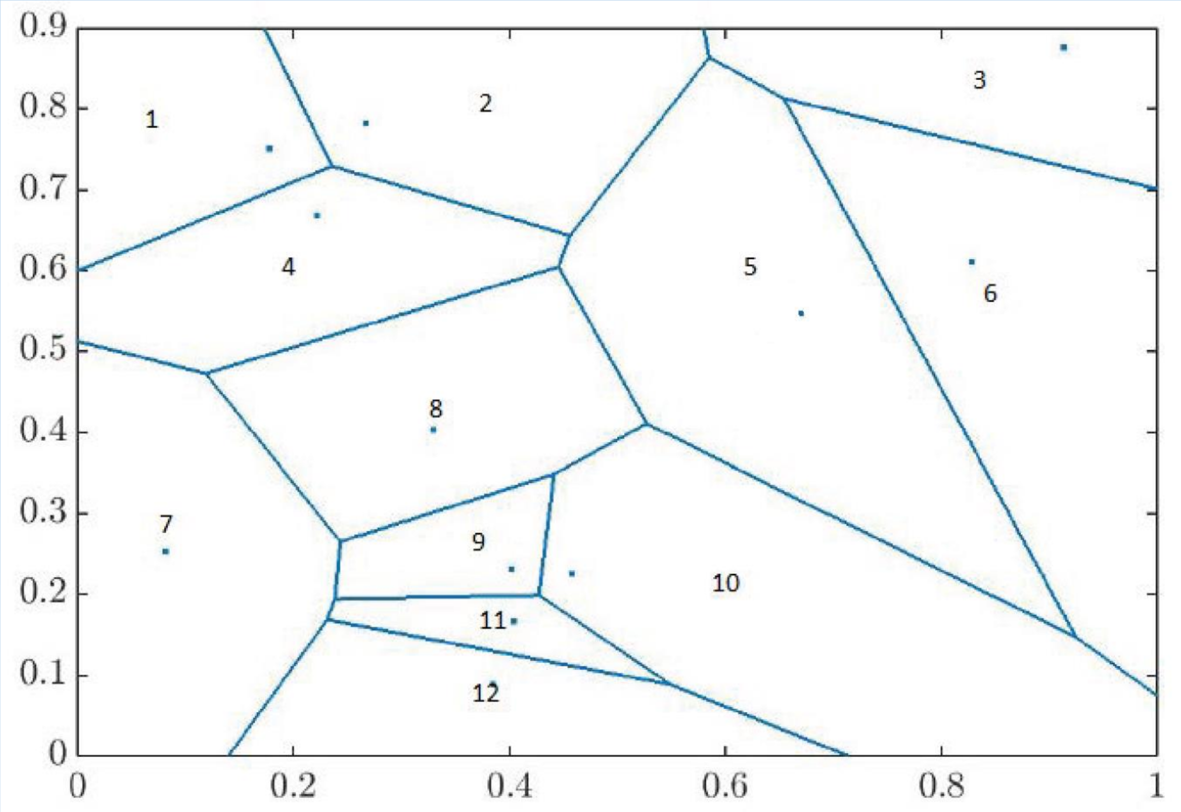
Wireless network case (random)

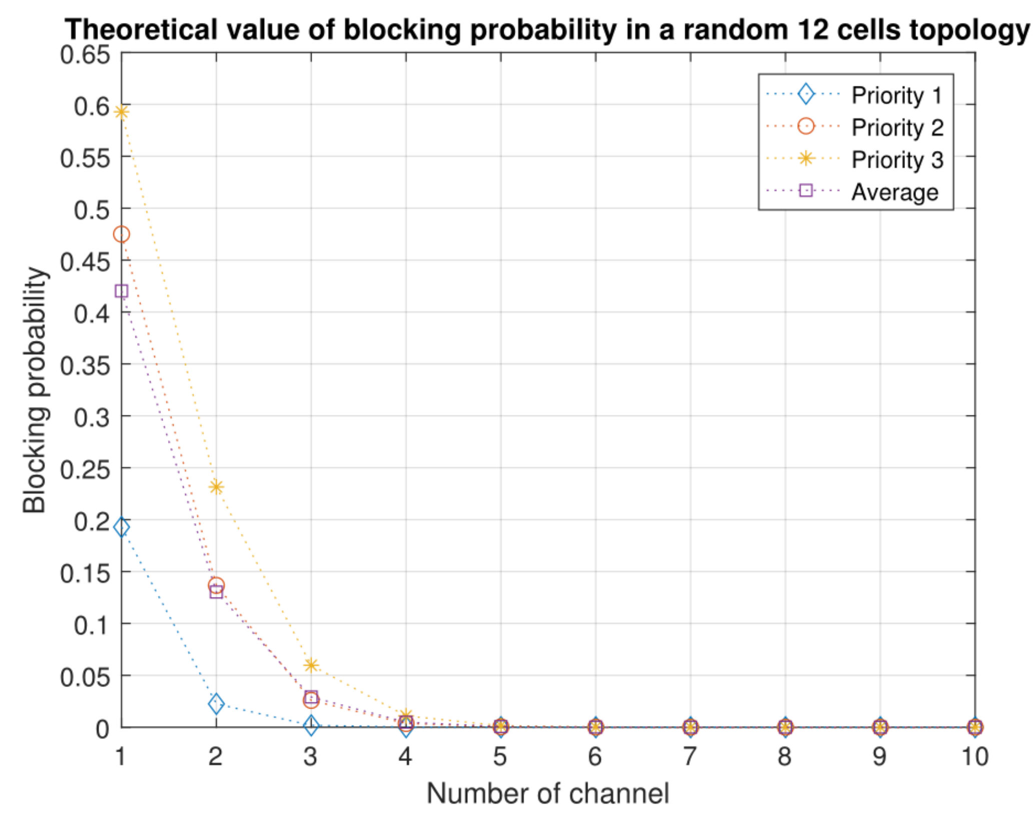


Random 12 cell topology

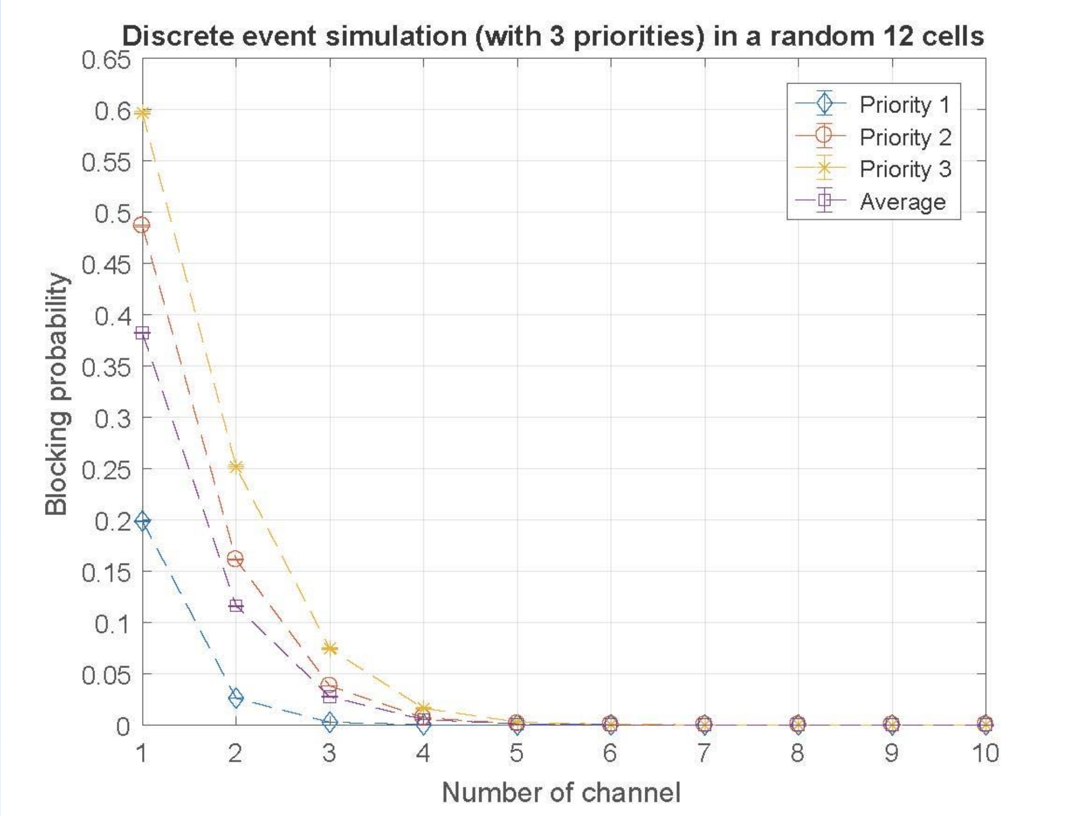
$$
P(i,j)_{random} = \begin{bmatrix}
0 & 1/2 & 0 & 1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/4 & 0 & 1/4 & 1/4 & 1/4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1/3 & 0 & 0 & 1/3 & 1/3 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/5 & 1/5 & 0 & 0 & 1/5 & 0 & 1/5 & 1/5 & 0 & 0 & 0 & 0 \\
0 & 1/6 & 1/6 & 1/6 & 0 & 1/6 & 0 & 1/6 & 0 & 1/6 & 0 & 0 \\
0 & 0 & 1/3 & 0 & 1/3 & 0 & 0 & 0 & 0 & 1/3 & 0 & 0 \\
0 & 0 & 0 & 1/5 & 0 & 0 & 0 & 1/5 & 1/5 & 0 & 1/5 & 1/5 \\
0 & 0 & 0 & 1/5 & 1/5 & 0 & 1/5 & 0 & 1/5 & 1/5 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1/4 & 1/4 & 0 & 1/4 & 1/4 & 0 \\
0 & 0 & 0 & 0 & 1/6 & 1/6 & 0 & 1/6 & 1/6 & 0 & 1/6 & 1/6 \\
0 & 0 & 0 & 0 & 0 & 0 & 1/4 & 0 & 1/4 & 1/4 & 0 & 1/4 \\
0 & 0 & 0 & 0 & 0 & 0 & 1/3 & 0 & 0 & 1/3 & 1/3 & 0
\end{bmatrix}
$$

Adjacent matrix of handover

Calculation and simulation results (random)



Theoretical calculation



Simulation result

ISPs' cost saving effect

The lowest circuit L: meet the demand of lowest QoS (e.g. 15% Bp).

The highest circuit H: meet the demand highest QoS (e.g. 5% Bp).

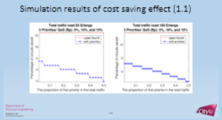
The cost can be saved is then: (H −L)/H.

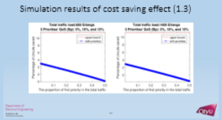
Procedure: the Priority 1 traffic start from the 1 Erlang, and gradually increased 1 Erlang to the half total offered load, the Priority 2 traffic always set to be the half of the Priority 1 traffic, and the remaining is Priority 3 traffic.

Simulation results of ISPs’ cost saving effect

- Group 1:

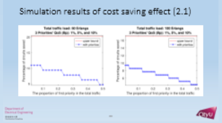
Three QoS tiers: 5%, 10%, 15%

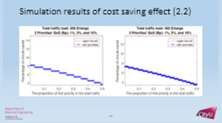


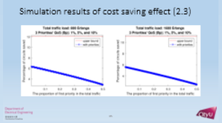


- Group 2:

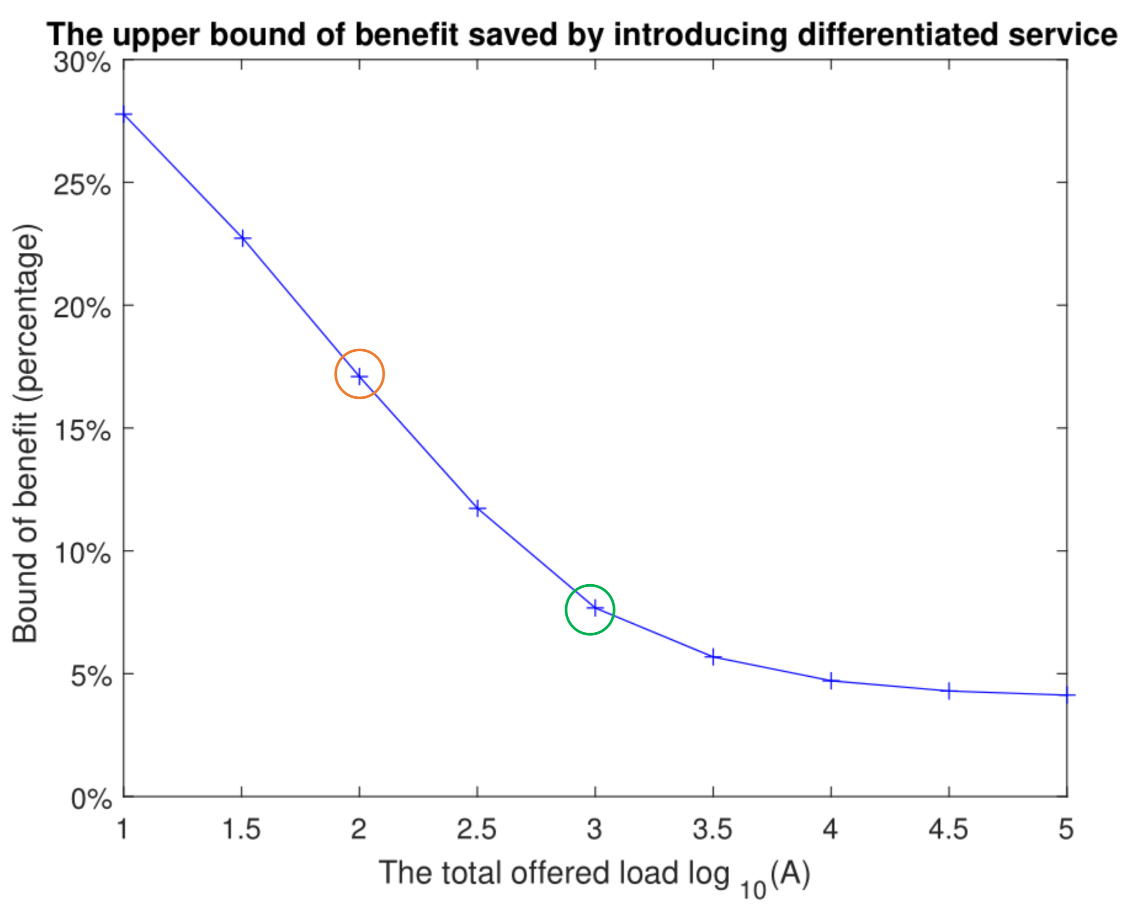
Three QoS tiers: 1%, 5%, 10%







The trend of upper-bound respect to the total offer load



The benefit of capacity saving decreases when the offered load goes up. For a local ISP whose offered load is 100 Erlangs, theoretically, it can save a maximum of 17% cost by introducing differentiated services, while if a local ISP's offered load is around 1000, then such percentage goes down to 7%.

(Note that the horizontal axis is in log-scale)

Impact of Introducing DS on End-users

- "Blocking probability" and "cost" is the main concern previously
- "Delay" is the metric from end-users' perspective
- Analytical tool: M/M/1-PS queueing model
- Using the same traffic assumption as previous:

  Packet size is 1400 Bytes (11200 bits), average number of packets is 800. The capacity of each channel is 10 Gbps
- The processing rate of this queueing model:

$$\mu = 10 \times 10^9 / (1400 \times 8 \times 800) = 1116.07$$

Delay – theoretical calculation

- The average delay of the M/M/1-PS system can be theoretically calculated by the following equation:

$$E[D] = \frac{1}{\mu - \lambda}$$

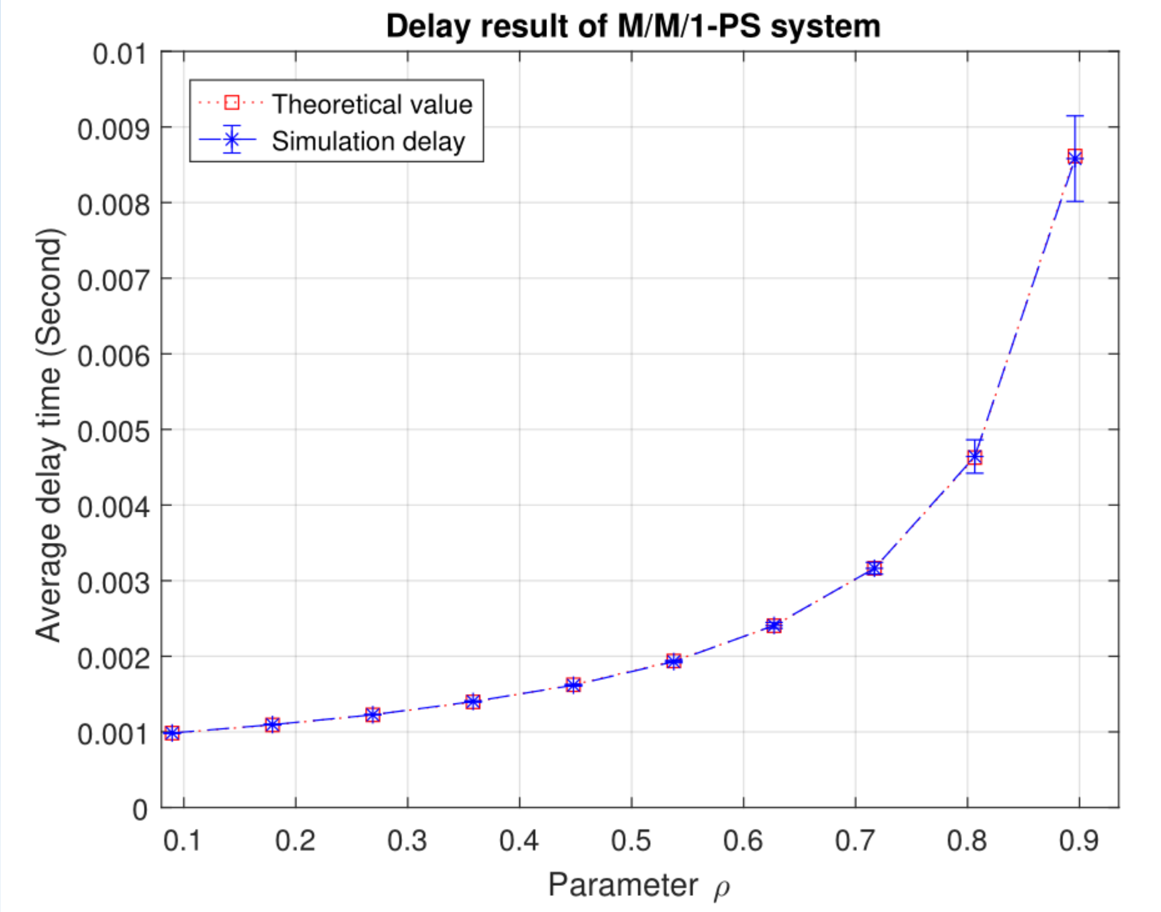
In case there is two priorities in the M/M/1-PS system, the delay can be calculated by:

$w_1 = \frac{1}{\mu - \lambda_1}$ where w_1 is the delay of P 1 and λ_1 is the arrival rate of P1

and

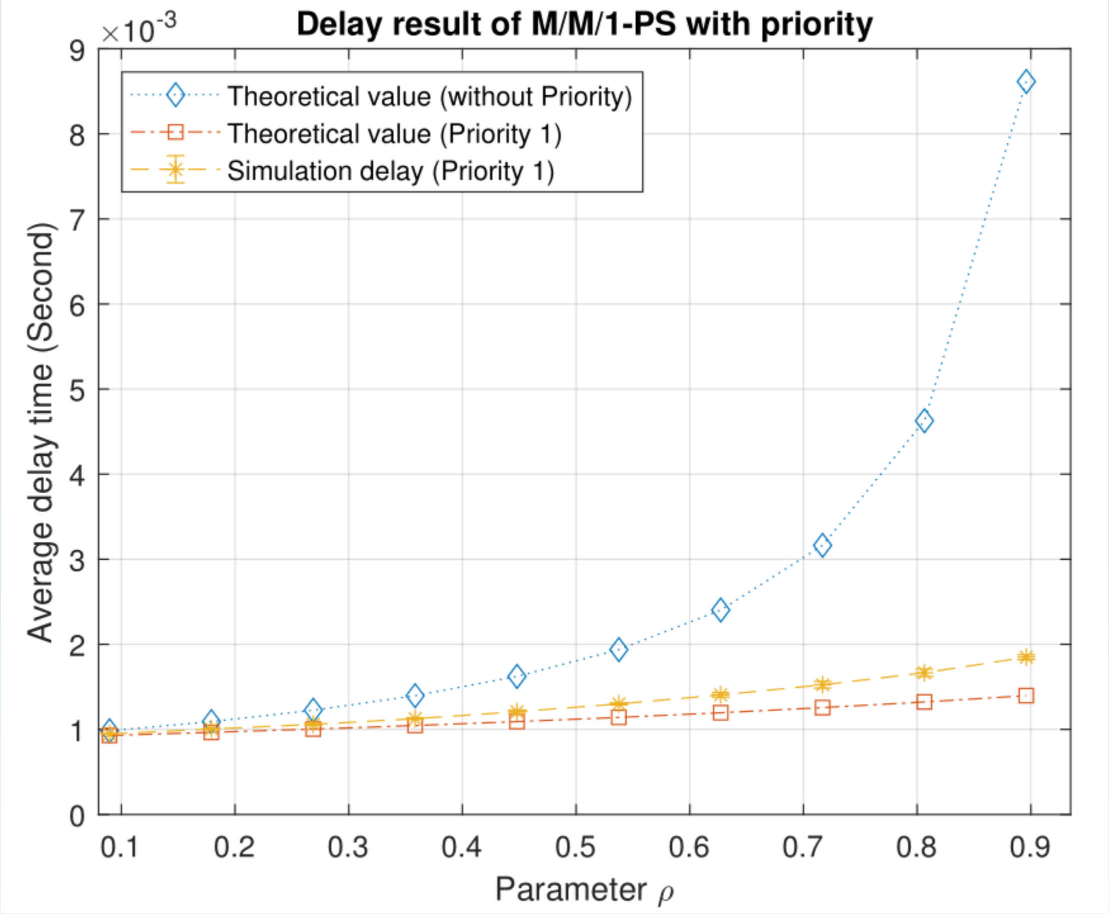
$w_2 = \frac{\mu}{\mu - \lambda} w_1 = \frac{\mu}{\mu - \lambda} \frac{1}{\mu - \lambda_1}$ where λ is the total arrival rate ($\lambda = \lambda_1 + \lambda_2$)

Analytical and simulation results of M/M/1-PS system



ρ	Theoretical value	Simulation result
0.0896	0.0009842	0.0009860
0.1792	0.0010916	0.0010964
0.2688	0.0012254	0.0012265
0.3584	0.0013965	0.0014023
0.448	0.0016232	0.0016172
0.5376	0.0019377	0.0019292
0.6272	0.0024034	0.0024082
0.7168	0.0031638	0.0031639
0.8064	0.0046281	0.0046423
0.896	0.0086154	0.0085819

M/M/1-PS system with 3 priorities



P1: 40% total traffic
P2: 50% total traffic
P3: 10% total traffic

when the traffic load is small ($\rho \approx 0.1$), the highest priority can save 3.88 % of the waiting time, and when the traffic load is high ($\rho \approx 0.9$), the highest priority can save nearly 80% of the waiting time.

Comparative analysis of service differentiation based on real datasets

- Now we investigate the impact of differentiated services on network services from the dimension of service types (protocols)
- Different protocols serve different transmission, using different protocols simultaneously is accepted as a SOCIAL NORM

Datasets used:

Group 1: (http://mawi.wide.ad.jp/mawi/, Sample point F, Japan)

1. "WIDE_20150917_130700"
2. "WIDE_20180621_130000"
3. "WIDE_20200315_130140"
4. "WIDE_20200316_130640"
5. "WIDE_20200316_131000"

Group 2: (https://data.caida.org/datasets/passive-2015/equinix-chicago.dirA/)

1. "20150219-131200/UTC.anon.pcap"
2. "20150521-130800/UTC.anon.pcap"
3. "20150917-130800/UTC.anon.pcap"
4. "20151217-131800/UTC.anon.pcap"

Group 3: (https://data.caida.org/datasets/passive-2016/equinix-chicago.dirA/)

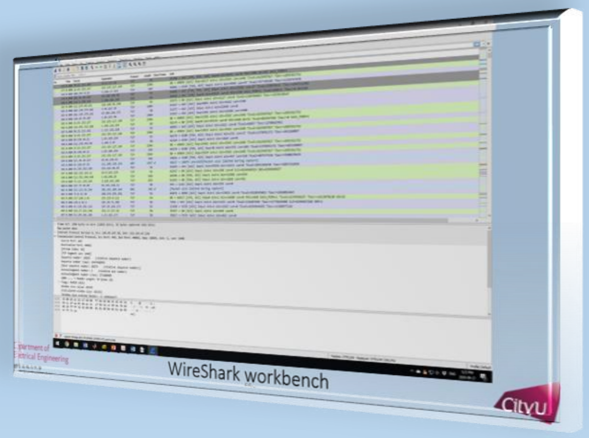
1. "20160121-132200/UTC.anon.pcap"
2. "20160218-131200/UTC.anon.pcap"
3. "20160317-131000/UTC.anon.pcap"
4. "20160406-131000/UTC.anon.pcap"

Group 4: (https://data.caida.org/datasets/passive-2018/equinix-nyc.dirA/)

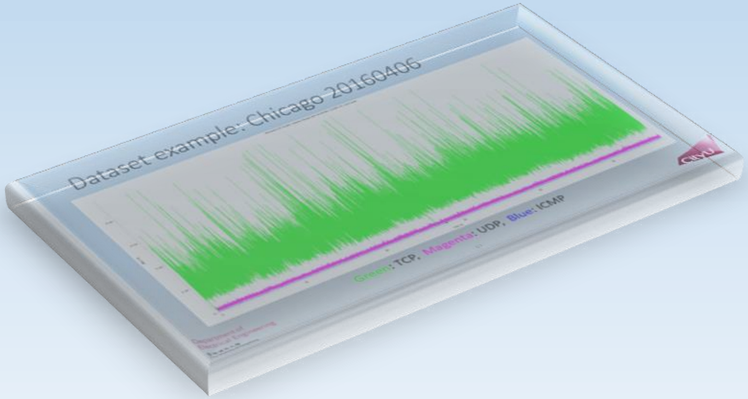
1. "20180315-130200/UTC.anon.pcap"
2. "20180419-131300/UTC.anon.pcap"
3. "20180517-133800/UTC.anon.pcap"
4. "20180621-134500/UTC.anon.pcap"
5. "20180719-132300/UTC.anon.pcap"
6. "20180816-133200/UTC.anon.pcap"

Data analysis tool and 3 scenarios

- Data analytical tool: Wireshark



- Dataset plot:



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Capacity dimensioning of 3 schemes

The capacity needed for each dataset is calculated by the follow equation:

$$\text{Capacity} = \text{mean(Traffic Volume)} + k \times \text{std(Traffic Volume)}$$

We consider 3 schemes:

1. The net neutrality (NN) scheme (FCFS)
2. The dedicated line scheme
3. The preemptive priority scheme

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The NN scheme with FCFS

- Mean of traffic volume (M) + k times of standard deviation (SD), (k = 1, initiative value)
- Derive the blocking probability of all the traffic
- Increase the value k of SD in step of 0.1 until the blocking probability of all protocol traffic is less than 0.25%.

We set 0.25% blocking as an acceptable QoS (benchmark)

The dedicated line scheme

- Keep the same total capacity C in the NN scheme
- Calculate the dedicated capacity C_U and relevant k_U value for UDP traffic, make sure Pb_U is less or equal to 0.25%
- The remaining capacity $C\_R = C - C\_U$, serve the ICMP and TCP traffic
- Derive the blocking probability of ICMP and TCP, respectively

The preemptive priority schemes

- Keep the same total capacity C in the NN scenario.
- Assign the priority to traffic: 1-ICMP, 2-UDP, 3-TCP.
- Calculate the blocking probability of each groups.

Numerical results: discard overflow TCP traffic:

Dataset	Net Neutrality Scheme (FCFS)			Dedicated Line Scheme					Preemptive Priority Scheme			
	k value	total capacity (bps)	BP (all)	k_U value	Total Capacity (bps)	UDP Capacity (bps)	BP (ICMP + TCP)	BP (UDP)	Total Capacity (bps)	BP (ICMP)	BP (UDP)	BP (TCP)
WIDE_20200315_130140	4.6	1135694447	0.2260%	6.6	1135694447	77677413.9	0.6940%	0.2500%	1135694447	0.0000%	0.0000%	0.2710%
WIDE_20200316_130640	2.7	1556114015	0.2210%	7	1556114015	343652361	0.0040%	0.2470%	1556114015	0.0000%	0.0000%	0.2690%
WIDE_20200316_131000	2.9	1618127364	0.2420%	3.8	1618127364	443909615	1.8640%	0.2500%	1618127364	0.0000%	0.0000%	0.3580%
WIDE_20180621_130000	3.3	9033657191	0.0833%	3.2	9033657191	988293149	0.5300%	0.2467%	9033657191	0.0000%	0.0000%	0.0883%
WIDE_20150917_132600	3.3	4567636161	0.2350%	3.2	4567636161	276026492	0.3300%	0.2333%	4567636161	0.0000%	0.0000%	0.2867%
Chicago_20150219_131200	3	5038689436	0.2300%	4.3	5038689436	555596095	0.4983%	0.2383%	5038689436	0.0000%	0.0000%	0.2450%
Chicago_20150521-130800	3.1	4968595418	0.2117%	3.5	4968595418	407819142	0.3683%	0.2500%	4968595418	0.0000%	0.0000%	0.2383%
Chicago_20150917-130800	3.2	4585662701	0.2467%	3.3	4585662701	296208120	0.3783%	0.2450%	4585662701	0.0000%	0.0000%	0.2750%
Chicago_20151217-131800	3.4	5426973895	0.2417%	3.1	5426973895	461568267	0.3683%	0.2233%	5426973895	0.0000%	0.0000%	0.3117%
Chicago_20160121-132200	3.7	6618986532	0.2367%	2.8	6618986532	414389878	0.2800%	0.2400%	6618986532	0.0000%	0.0000%	0.2883%
Chicago_20160218-131200	5	8598858480	0.2397%	3.5	8598858480	421309918	0.2737%	0.2193%	8598858480	0.0000%	0.0000%	0.2822%
Chicago_20160317-131000	4.3	5817656895	0.2383%	5	5817656895	616813884	0.3383%	0.2500%	5817656895	0.0000%	0.0000%	0.3067%
Chicago_20160406-131000	3.8	6314069935	0.2476%	3	6314069935	355585946	0.2807%	0.2284%	6314069935	0.0000%	0.0000%	0.2911%
Nyc_20180315-130200	3.1	7551260026	0.2317%	3.3	7551260026	1013095406	0.5250%	0.2467%	7551260026	0.0000%	0.0000%	0.2800%
Nyc_20180419-131300	3.6	8748458664	0.2450%	2.8	8748458664	835613638	0.3900%	0.2433%	8748458664	0.0000%	0.0000%	0.2617%
Nyc_20180517-133800	2.6	9103611858	0.0000%	3.7	9103611858	1092725277	1.0000%	0.2467%	9103611858	0.0000%	0.0000%	0.0000%
Nyc_20180621-134500	3	9073991776	0.0000%	3	9073991776	963731056	0.5217%	0.2350%	9073991776	0.0000%	0.0000%	0.0000%
Nyc_20180719-132300	3.2	8785375551	0.2450%	2.8	8785375551	1020621984	0.4683%	0.2217%	8785375551	0.0000%	0.0000%	0.2550%
Nyc_20180816-133200	3	8739267603	0.2167%	2.7	8739267603	1153700382	0.4567%	0.2317%	8739267603	0.0000%	0.0000%	0.2350%

Numerical results: retransmit overflow TCP traffic:

Dataset	Net Neutrality Scheme (FCFS)			Dedicated Line Scheme					Preemptive Priority Scheme			
	k value	total capacity (bps)	BP (all)	k_U value	Total Capacity (bps)	UDP Capacity (bps)	BP (ICMP + TCP)	BP (UDP)	Total Capacity (bps)	BP (ICMP)	BP (UDP)	BP (TCP)
WIDE_20200315_130140	4.7	1155297024	0.2040%	6.6	1155297024	77677414	0.7200%	0.2500%	1155297024	0.0000%	0.0000%	0.2040%
WIDE_20200316_130640	2.8	1593980682	0.1920%	7	1593980682	343652361	1.6860%	0.2470%	1593980682	0.0000%	0.0000%	0.1920%
WIDE_20200316_131000	3.1	1693757514	0.2170%	3.8	1693757514	443909615	1.8930%	0.2500%	1693757514	0.0000%	0.0000%	0.2170%
WIDE_20180621_130000	3.3	9033657191	0.0883%	3.2	9033657191	988293149	0.5750%	0.2467%	9033657191	0.0000%	0.0000%	0.0883%
WIDE_20150917_132600	3.4	4648647295	0.2433%	3.2	4648647295	276026492	0.3350%	0.2333%	4648647295	0.0000%	0.0000%	0.2433%
Chicago_20150219_131200	3	5038689436	0.2450%	4.3	5038689436	555596095	0.5433%	0.2383%	5038689436	0.0000%	0.0000%	0.2450%
Chicago_20150521-130800	3.1	4968595418	0.2383%	3.5	4968595418	407819142	0.4283%	0.2500%	4968595418	0.0000%	0.0000%	0.2383%
Chicago_20150917-130800	3.3	4668473735	0.2283%	3.3	4668473735	296208120	0.3483%	0.2450%	4668473735	0.0000%	0.0000%	0.2283%
Chicago_20151217-131800	3.7	5671229225	0.2383%	3.1	5671229225	461568267	0.3367%	0.2233%	5671229225	0.0000%	0.0000%	0.2383%
Chicago_20160121-132200	3.8	6730067601	0.2500%	2.8	6730067601	414389878	0.3183%	0.2400%	6730067601	0.0000%	0.0000%	0.2500%
Chicago_20160218-131200	5.2	8808409568	0.2499%	3.5	8808409568	421309918	0.2924%	0.2193%	8808409568	0.0000%	0.0000%	0.2499%
Chicago_20160317-131000	4.7	6137692309	0.2383%	5	6137692309	616813884	0.3383%	0.2500%	6137692309	0.0000%	0.0000%	0.2383%
Chicago_20160406-131000	4.1	6608803522	0.2354%	3	6608803522	355585946	0.2772%	0.2284%	6608803522	0.0000%	0.0000%	0.2354%
Nyc_20180315-130200	3.2	7676368898	0.2317%	3.3	7676368898	1013095406	0.5367%	0.2467%	7676368898	0.0000%	0.0000%	0.2317%
Nyc_20180419-131300	3.7	8879166503	0.2150%	2.8	8879166503	835613638	0.3750%	0.2433%	8879166503	0.0000%	0.0000%	0.2150%
Nyc_20180517-133800	2.6	9103611858	0.0000%	3.7	9103611858	1092725277	1.1083%	0.2467%	9103611858	0.0000%	0.0000%	0.0000%
Nyc_20180621-134500	3	9073991776	0.0000%	3	9073991776	963731056	0.5700%	0.2350%	9073991776	0.0000%	0.0000%	0.0000%
Nyc_20180719-132300	3.3	8918341158	0.2100%	2.8	8918341158	1020621984	0.4417%	0.2217%	8918341158	0.0000%	0.0000%	0.2100%
Nyc_20180816-133200	3	8739267603	0.2350%	2.7	8739267603	1153700382	0.5117%	0.2317%	8739267603	0.0000%	0.0000%	0.2350%

Summary of applying DS in real datasets

- In the dedicated line scheme, the UDP traffic gets the dedicated capacity for its transmission, so that the capacity of ICMP and TCP is squeezed, hence the performance of ICMP and TCP is degraded.
- While keeping the total capacity the same, the preemptive scheme shows that the blocking probability of the ICMP and the UDP are controlled to be zero, and the blocking probability of TCP is still acceptable. This shows that service differentiation based on service protocol is feasible, without causing discomfort to end-users.

A public survey of net neutrality in Hong Kong and result analysis

A survey experiment of net neutrality policy

- Conducted through “MyCitizensPanel”
- Since November 2018
- Total 497 effective respondents
- Conducted anonymously
- 429 respondents (86% in total) are in the age range from 20 to 49
- 299 respondents (60% in total) are full-time employed

Terminologies

- Bandwidth hungry service
- Zero-rating
- Bandwidth throttling

Experiment Vignettes setting

		Zero-rating	
		NOT allowed	Allowed
Bandwidth throttling	NOT allowed	**Vignette 1**: Neutral Network	**Vignette 2**: Platform-prioritized Network
	Allowed	**Vignette 3**: User-prioritized Network	**Vignette 4**: Prioritized Network

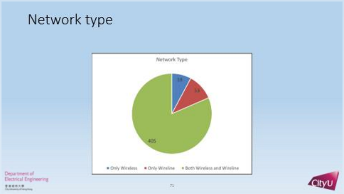
Six questions after reading vignettes

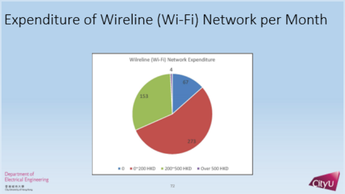
1. Satisfaction on current access rate
2. Agreement on zero-rating provided by ISPs
3. Agreement on effective strategy to maintain free-market of Hong Kong
4. Agreement on ISPs providing prioritized service based on price
5. Agreement on effective strategy for ISPs' incentive of invest and upgrade their infrastructure.
6. Agreement on importance of net neutrality policy to Hong Kong.

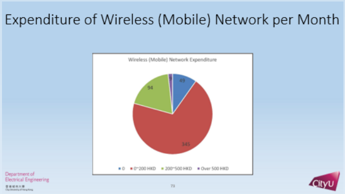
Answer is given by seven-point scale, where 1 = strongly disagree and 7 = strongly agree

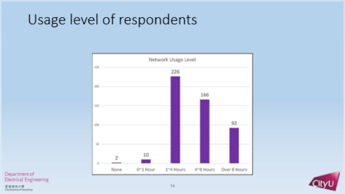
Survey results: preliminary questions

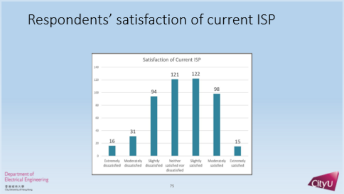
- Network type
- Expenditure of Wireline (Wi-Fi) Network per Month
- Expenditure of Wireless (Mobile) Network per Month
- Usage level of respondents
- Respondents’ satisfaction of current ISP





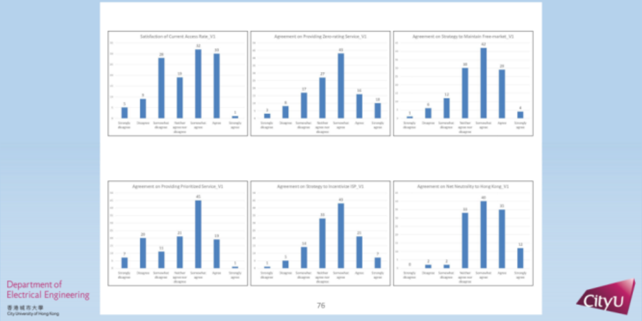




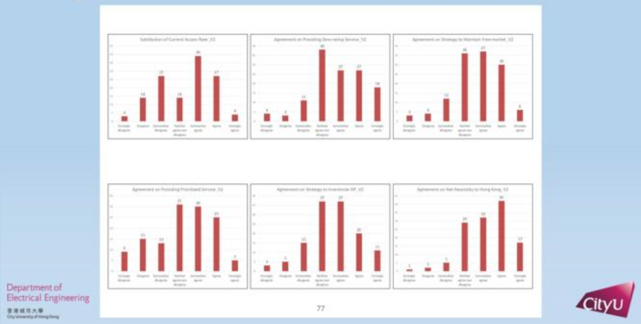


Survey results: response of six questions

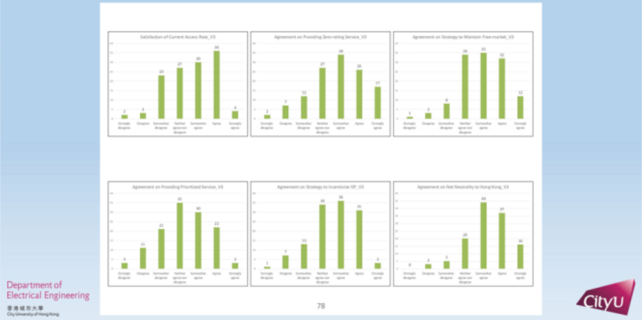
Vignette 1:



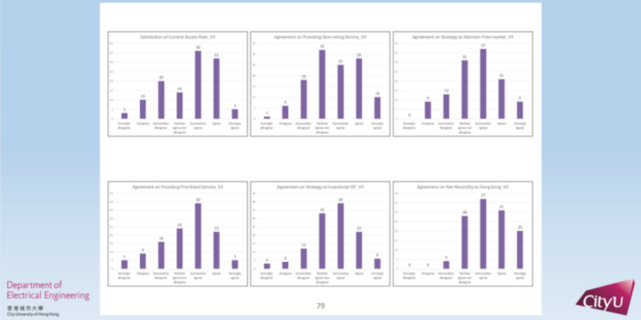
Vignette 2:



Vignette 3:



Vignette 4:



Survey results analysis (ANOVA)

	Vignette 1		Vignette 2		Vignette 3		Vignette 4	
	Average	Variance	Average	Variance	Average	Variance	Average	Variance
Q1	4.33	2.29	4.37	2.20	4.68	1.70	4.72	2.10
Q2	4.56	2.25	4.81	2.15	4.89	2.14	4.72	2.10
Q3	4.78	1.44	4.62	1.64	4.97	1.58	4.58	1.88
Q4	4.05	2.72	4.15	2.52	4.23	2.02	4.39	2.20
Q5	4.62	1.59	4.59	1.73	4.60	1.63	4.61	1.57
Q6	5.24	1.15	5.23	1.40	5.26	1.32	5.32	1.22

Conclusions

- Review the definition and some historical event of net neutrality
- From a multi-layer structure perspective, reviewed the realization of differentiated services
- Analyze the impact of differentiated services from the angle of ISPs and users through queuing theory
- Evaluate differentiated services through real data sets
- Carried out a public survey of net neutrality policy

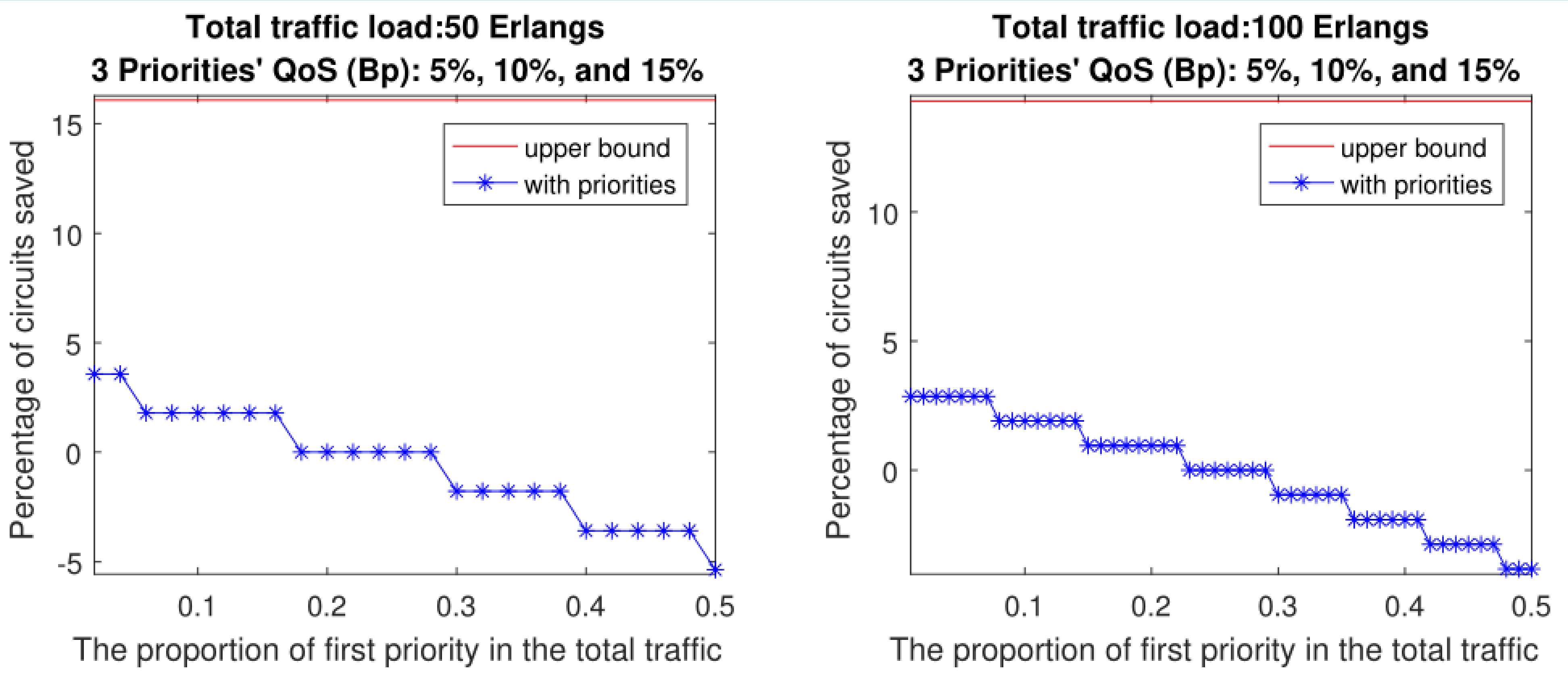
Future work

1. More accurate queueing models: “soft blocking” in data networks
2. New ecosystem of Internet services, much of the users also play the role of “content providers”. (YouTube live, TikTok, ect.)
3. A two-way survey will form a complete picture of the opinions on net neutrality

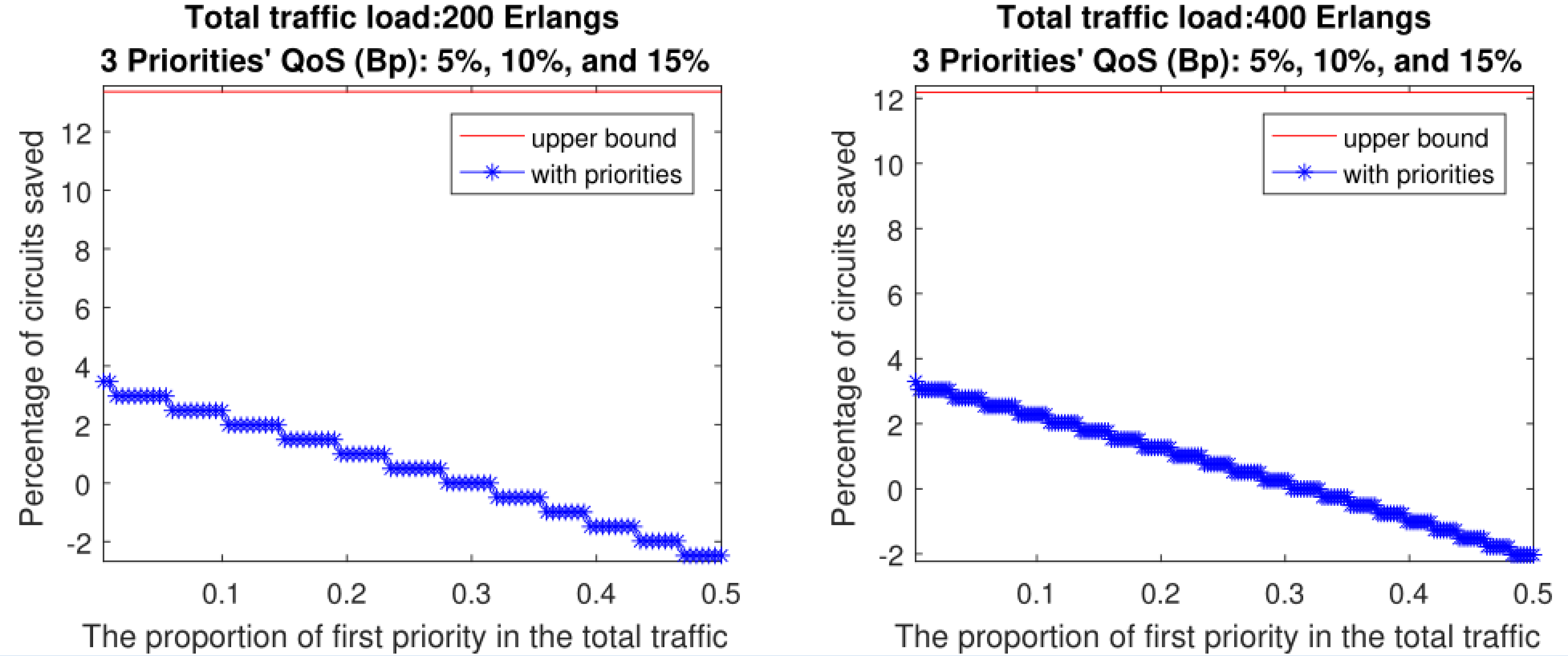
Thank you!

Q & A

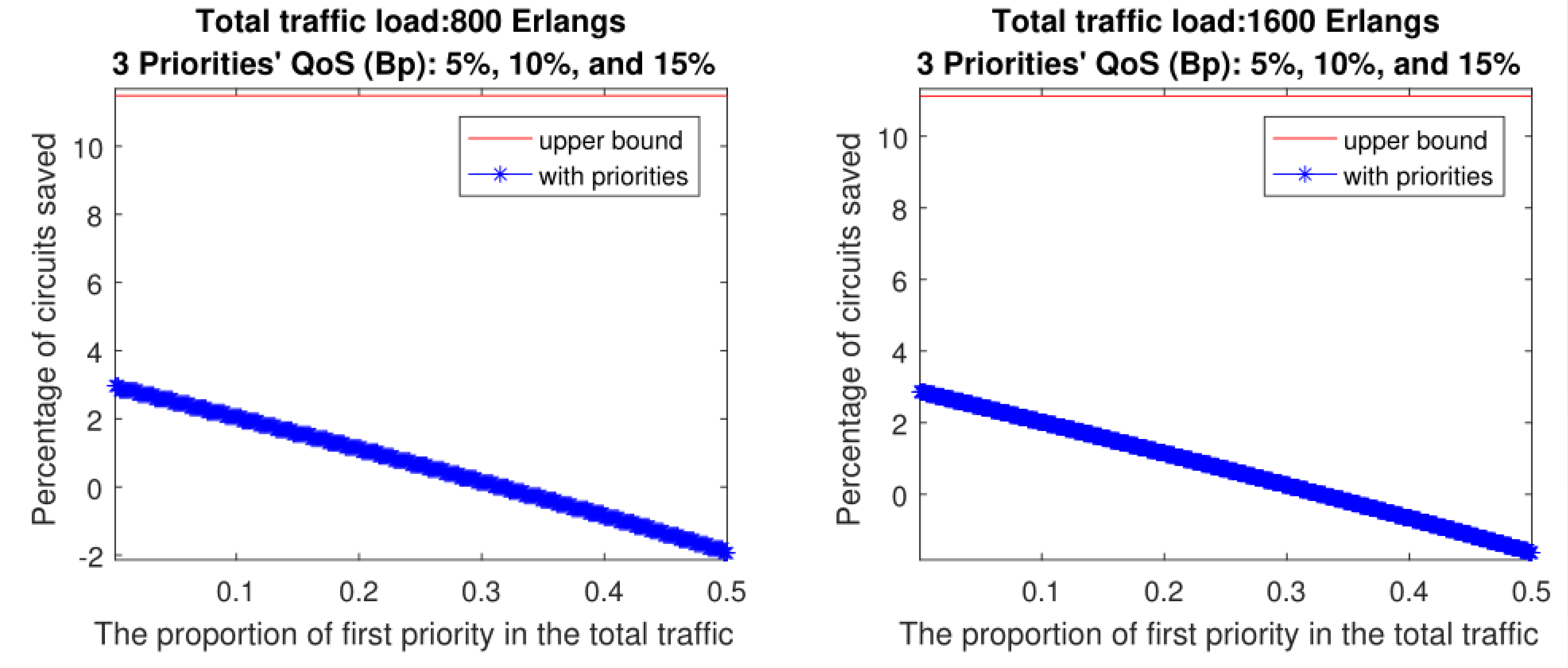
Simulation results of cost saving effect (1.1)



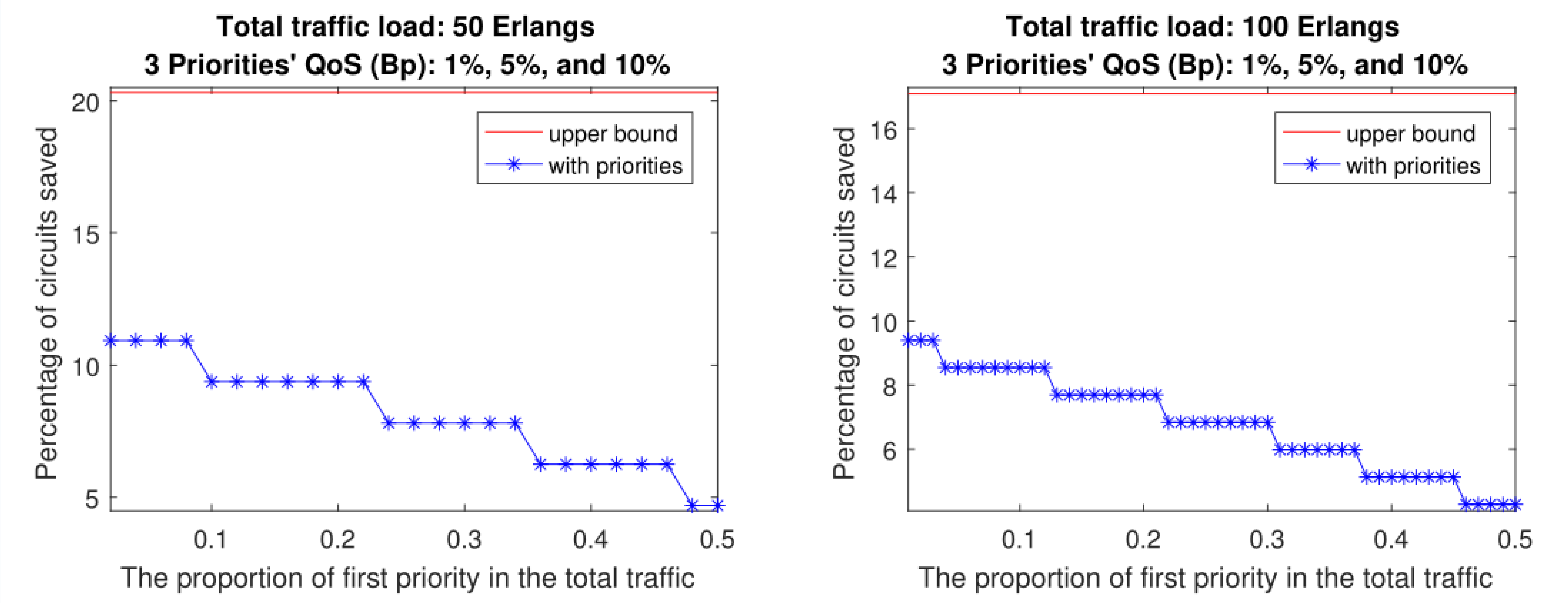
Simulation results of cost saving effect (1.2)



Simulation results of cost saving effect (1.3)



Simulation results of cost saving effect (2.1)



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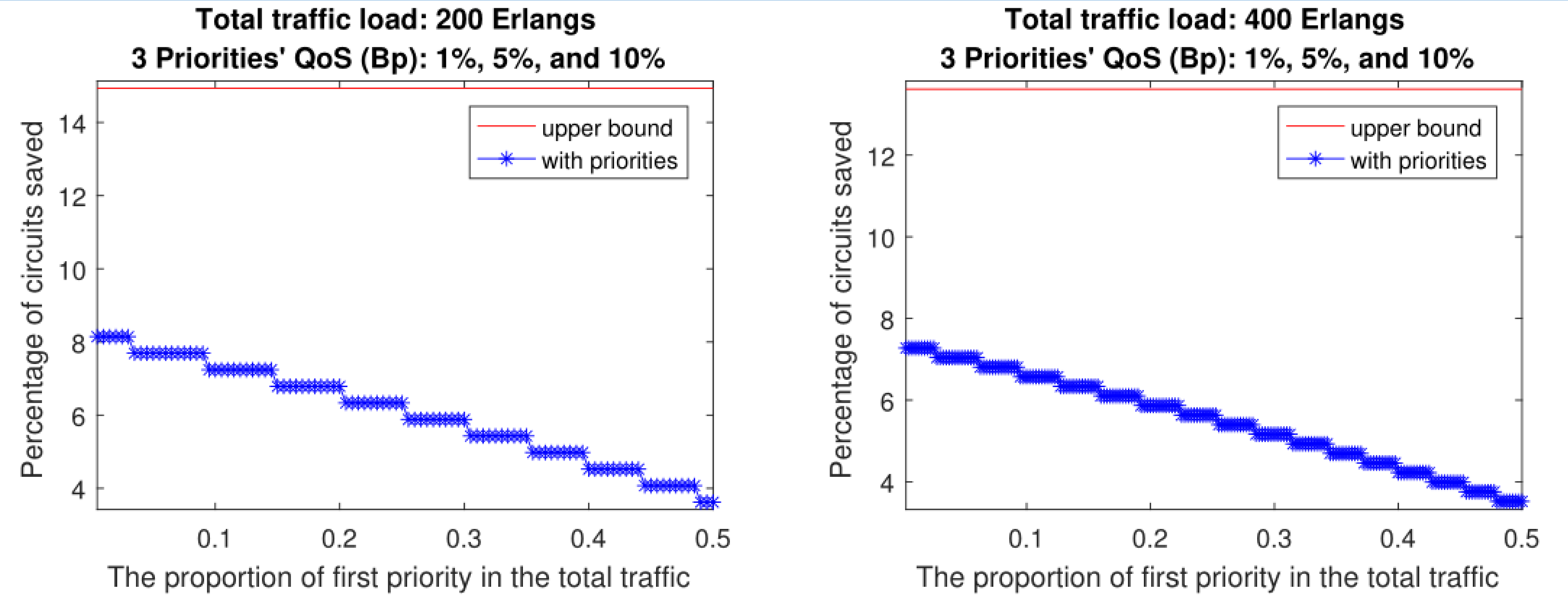
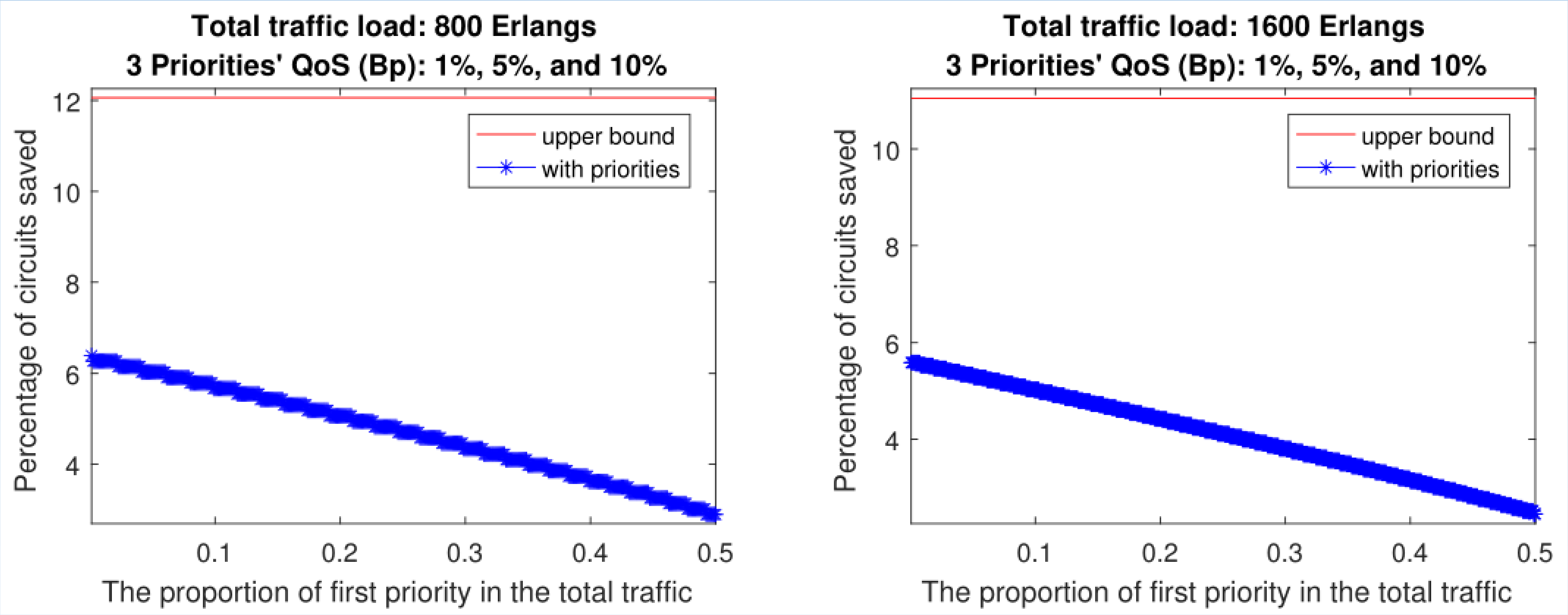
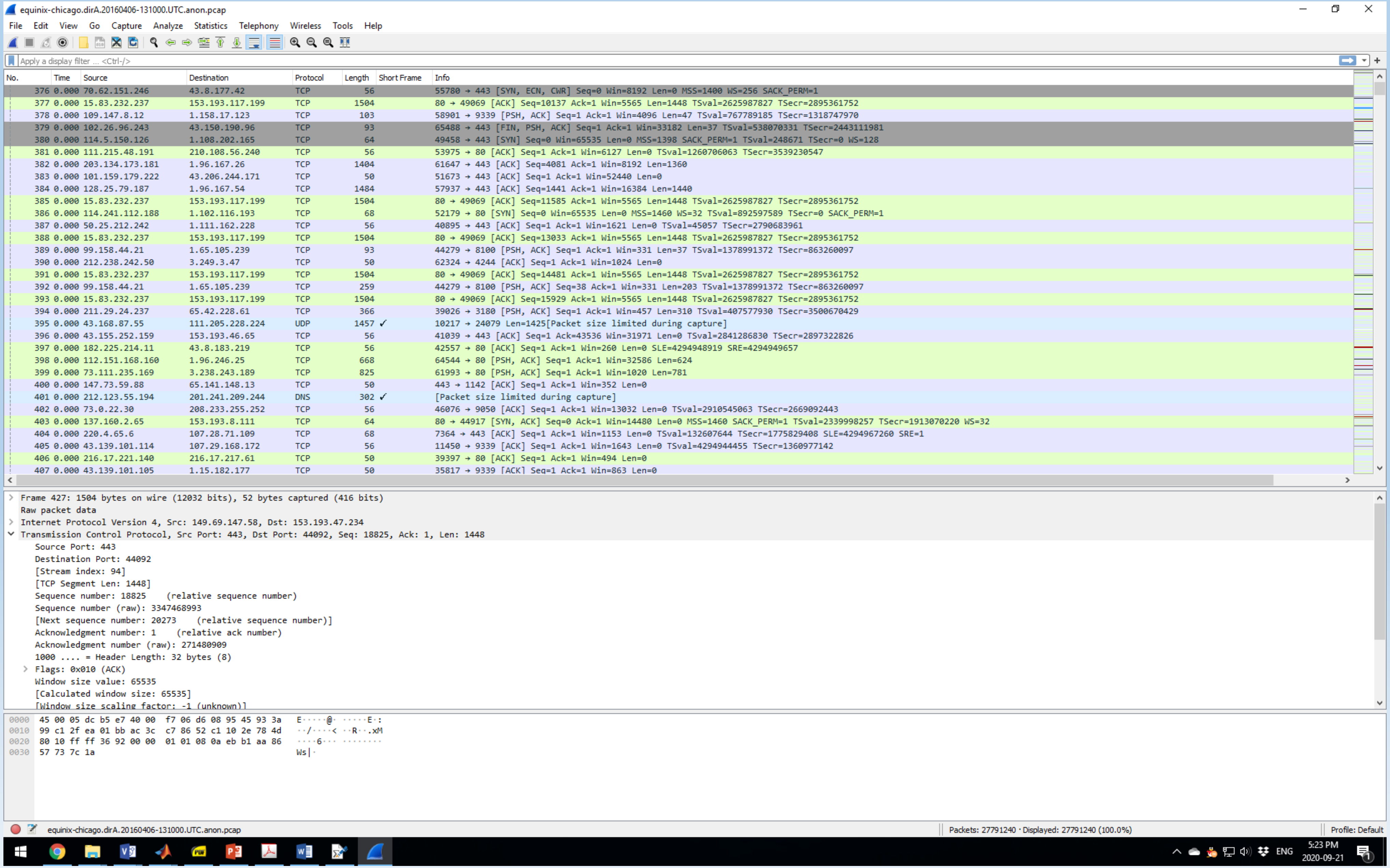
Simulation results of cost saving effect (2.2)



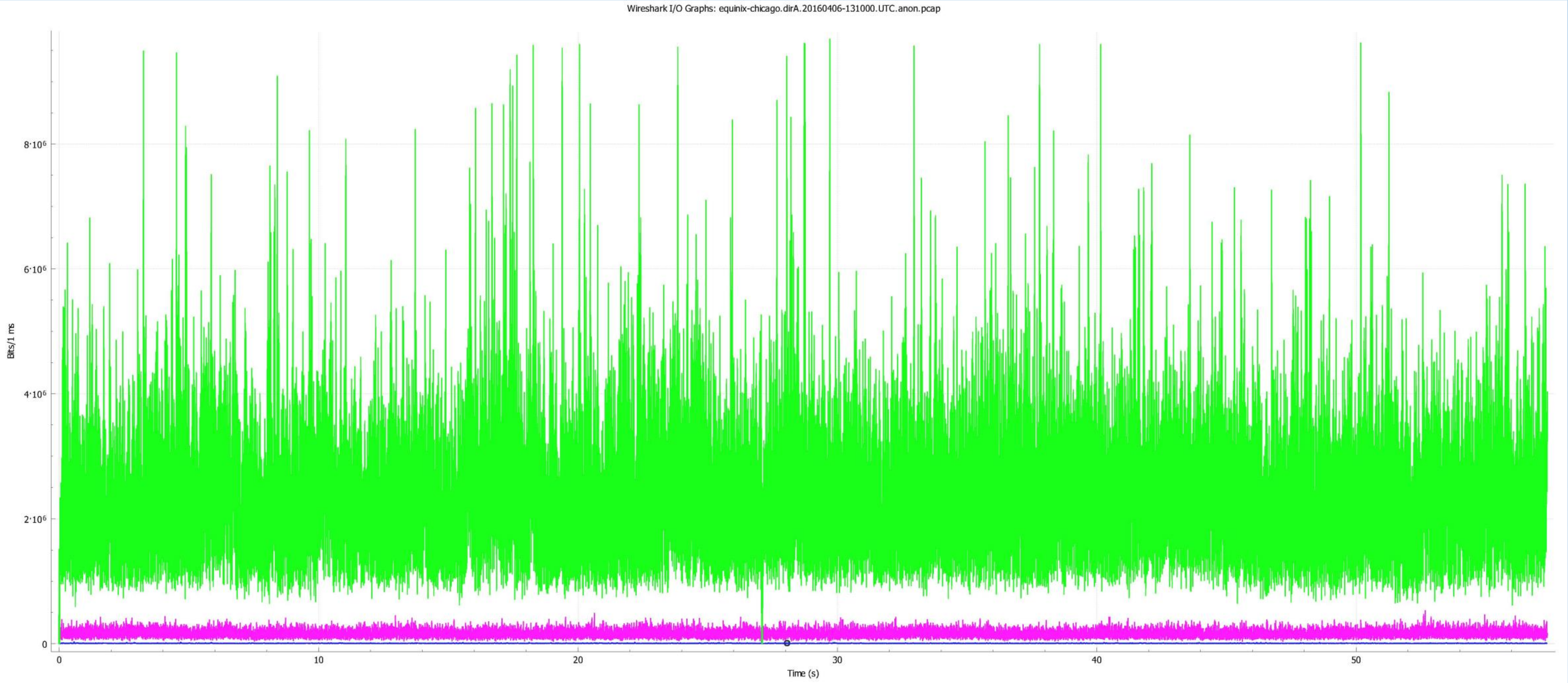
Simulation results of cost saving effect (2.3)





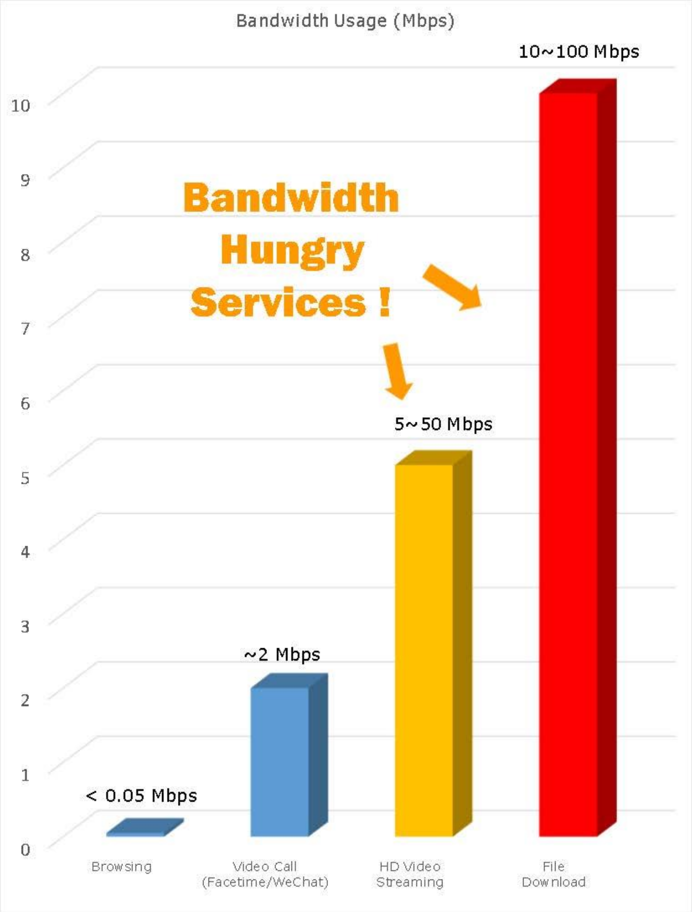
WireShark workbench

Dataset example: Chicago 20160406



Green: TCP, Magenta: UDP, Blue: ICMP

Bandwidth hungry service

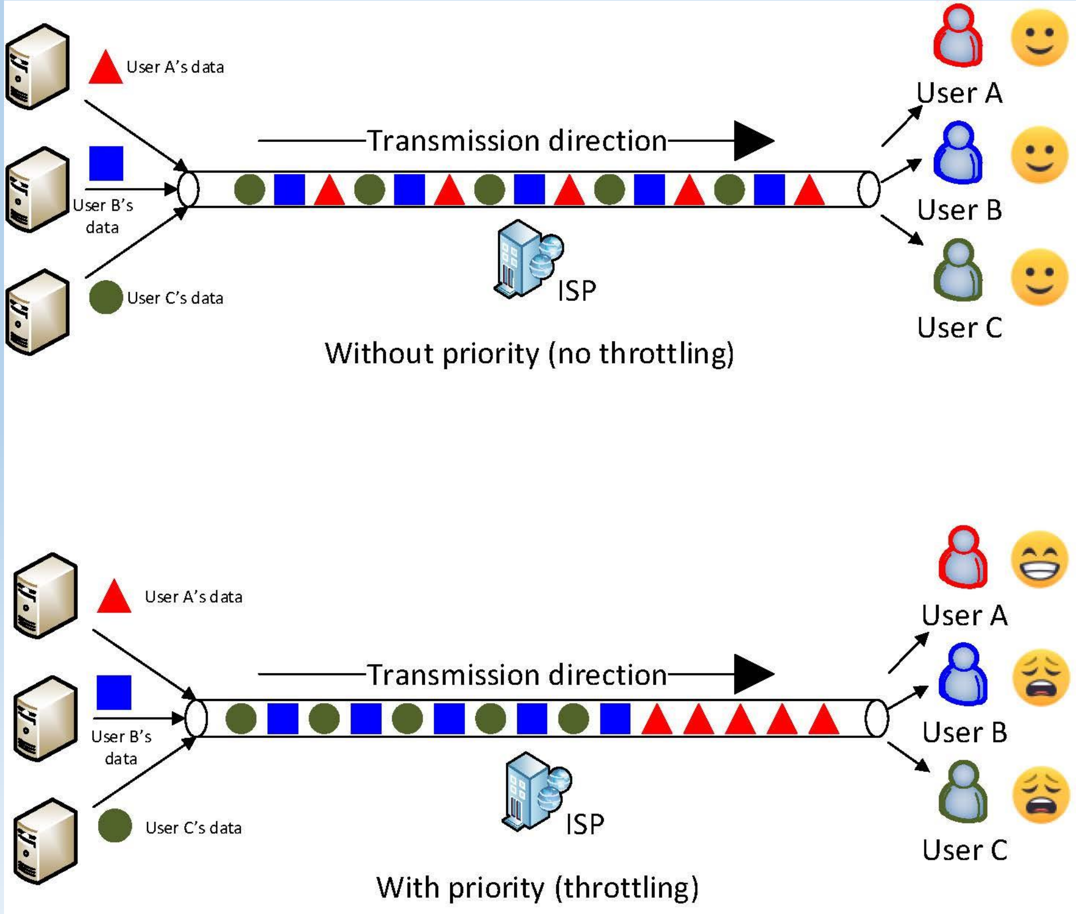


- Bandwidth hungry services: Applications that require large amount of data transmission and therefore consume significant amount of network resources

Zero-rating

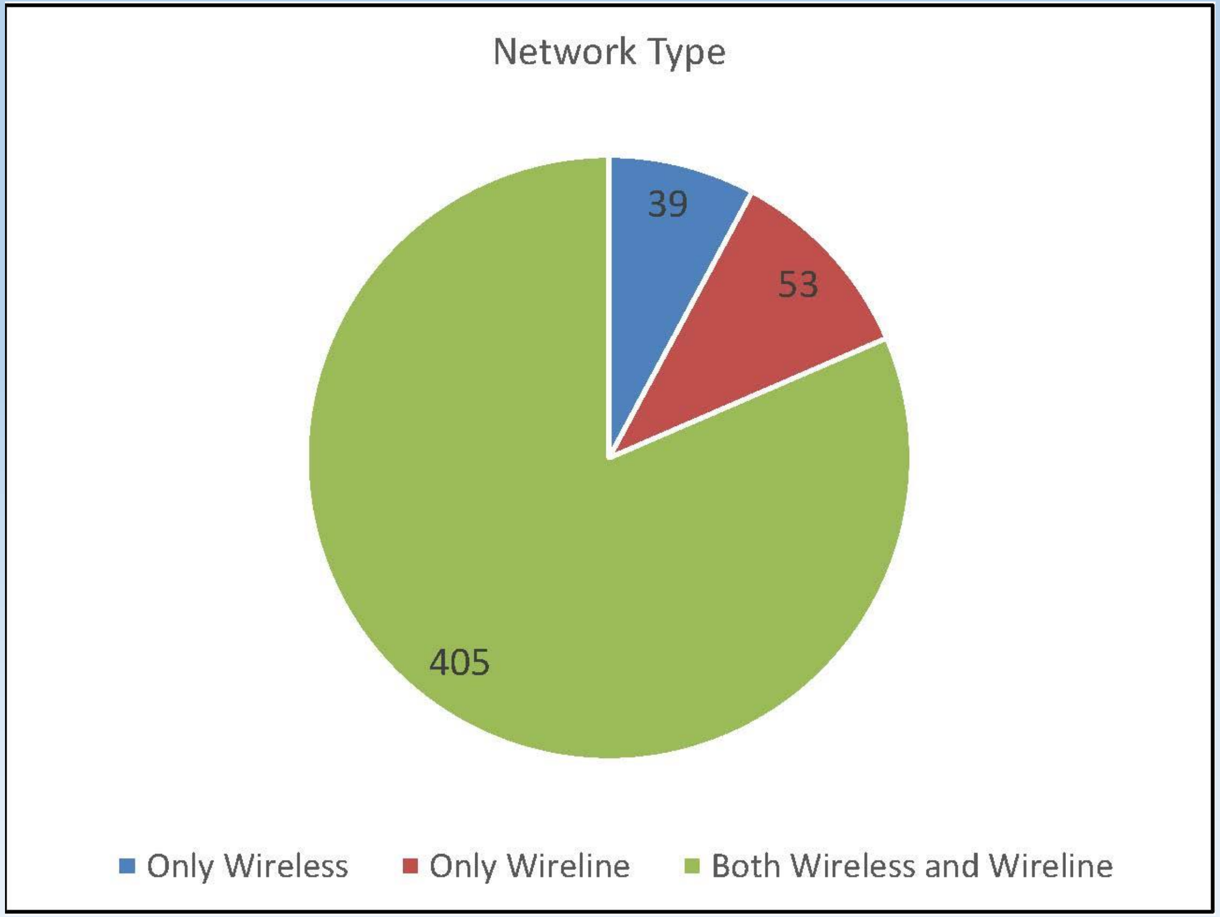
- A benefit that an internet service provider may offer to their subscribers, who are able to access certain websites, services or applications without being charged, also called “toll-free” (Example: The Wikipedia website is free to access when using mobile devices in some countries)

Bandwidth throttling

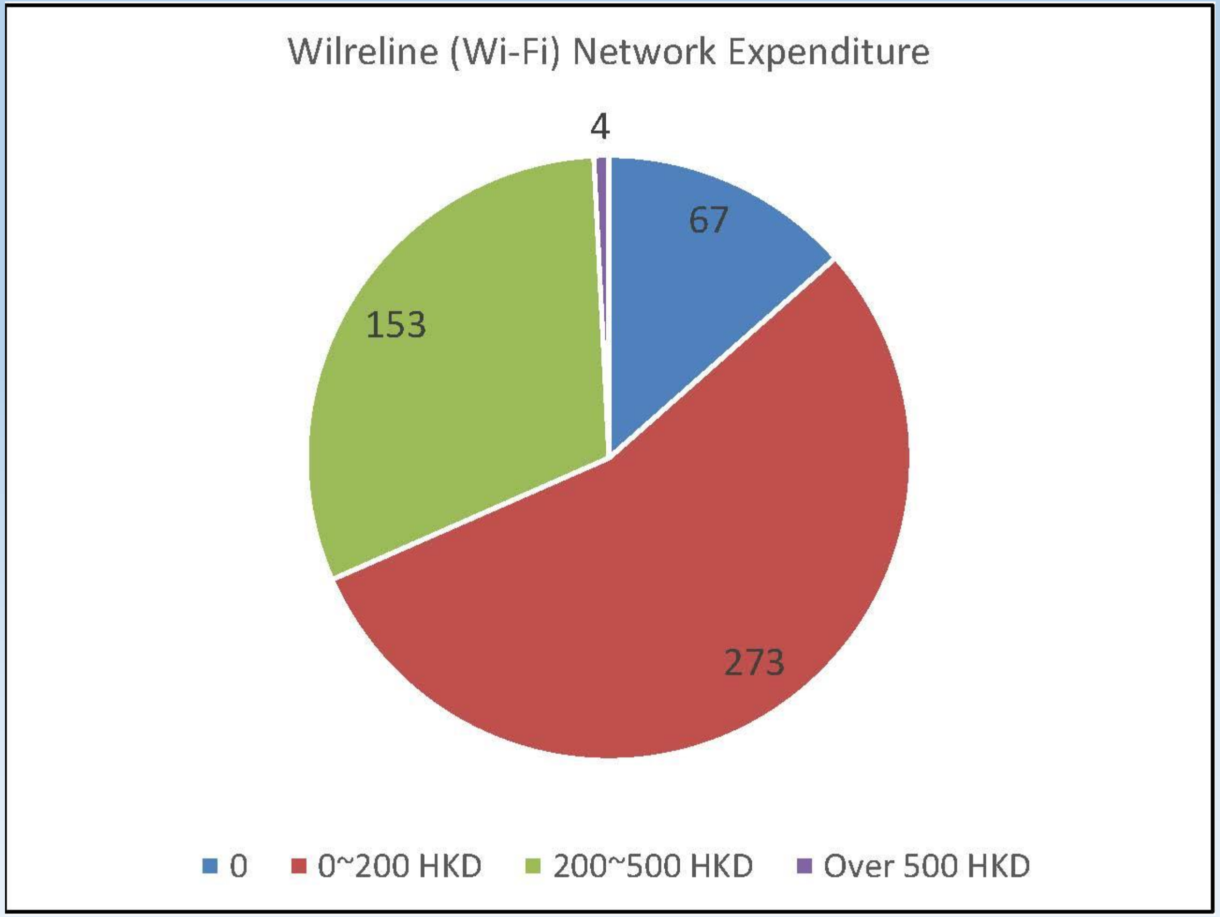


- Bandwidth throttling: An action by an internet service provider to increase or decrease the speed of an internet service.
- Bandwidth throttling under and not under network congestion: Bandwidth throttling can be done either under congestion or no congestion conditions. Under congestion, the internet service provider may allow customers who pay more to have priority over other customers, so the traffic of those customers who pay less will suffer a longer delay or even lose connection. Under no congestion, internet service providers may reduce the rate of certain customers, who for example exceed the monthly data cap according to their plan, which can be higher or lower depending on the payment.

Network type



Expenditure of Wireline (Wi-Fi) Network per Month



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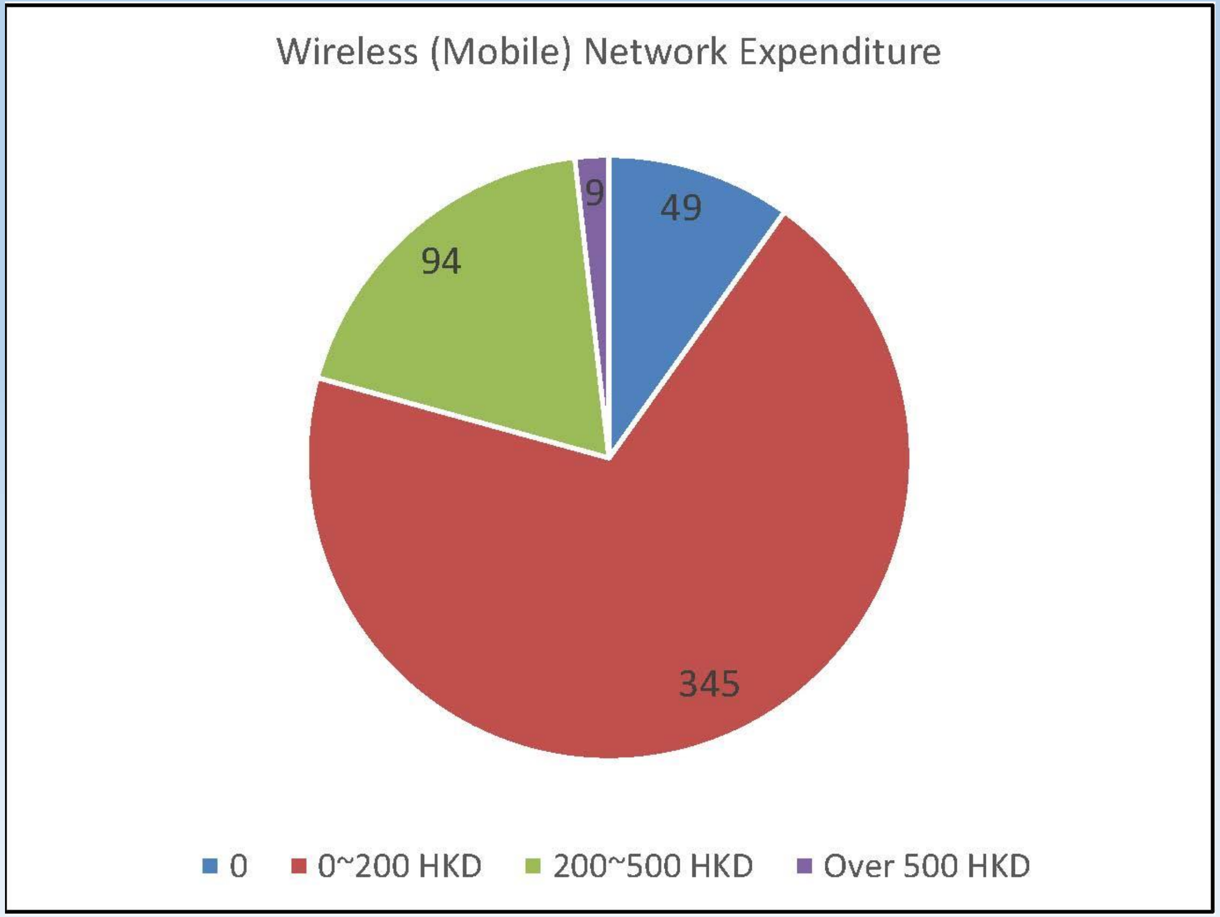
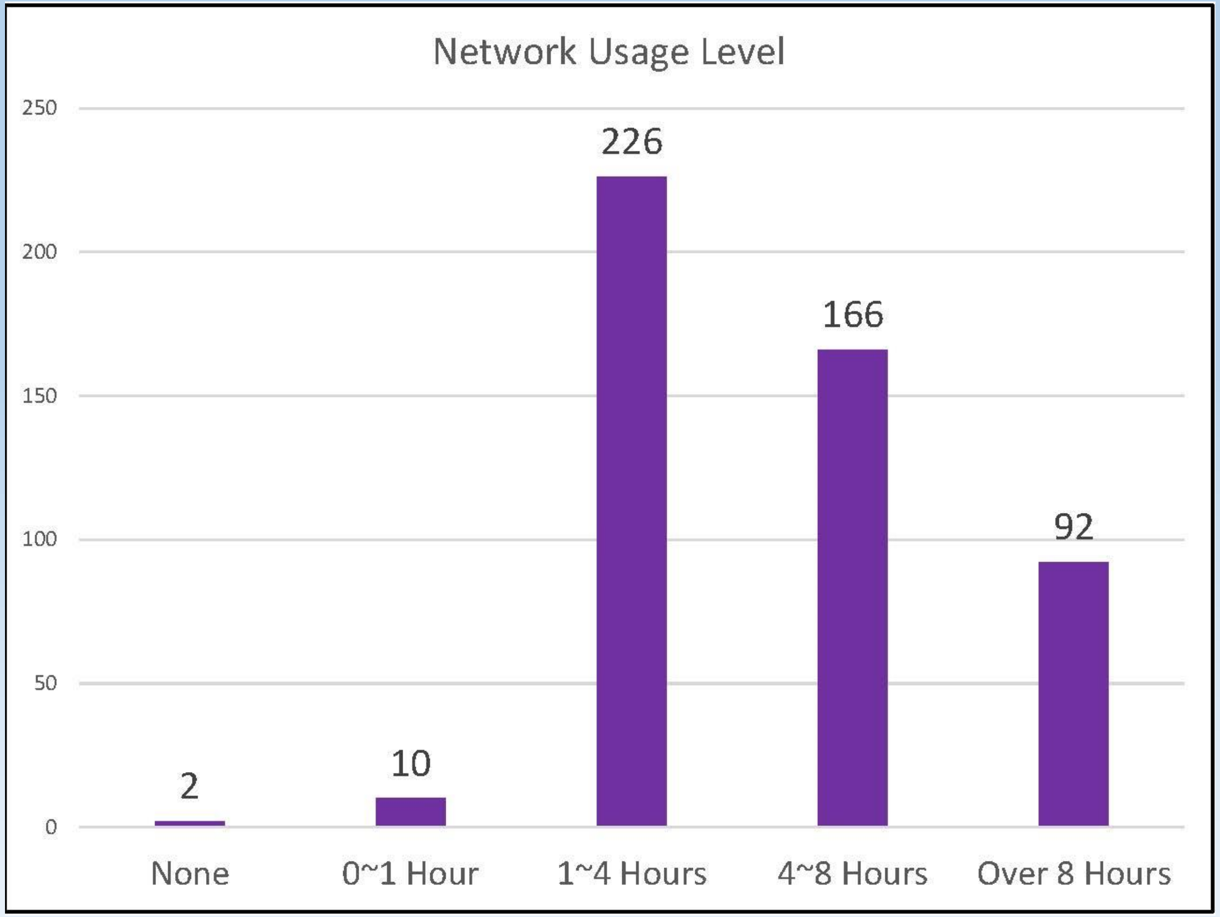
Expenditure of Wireless (Mobile) Network per Month



Usage level of respondents



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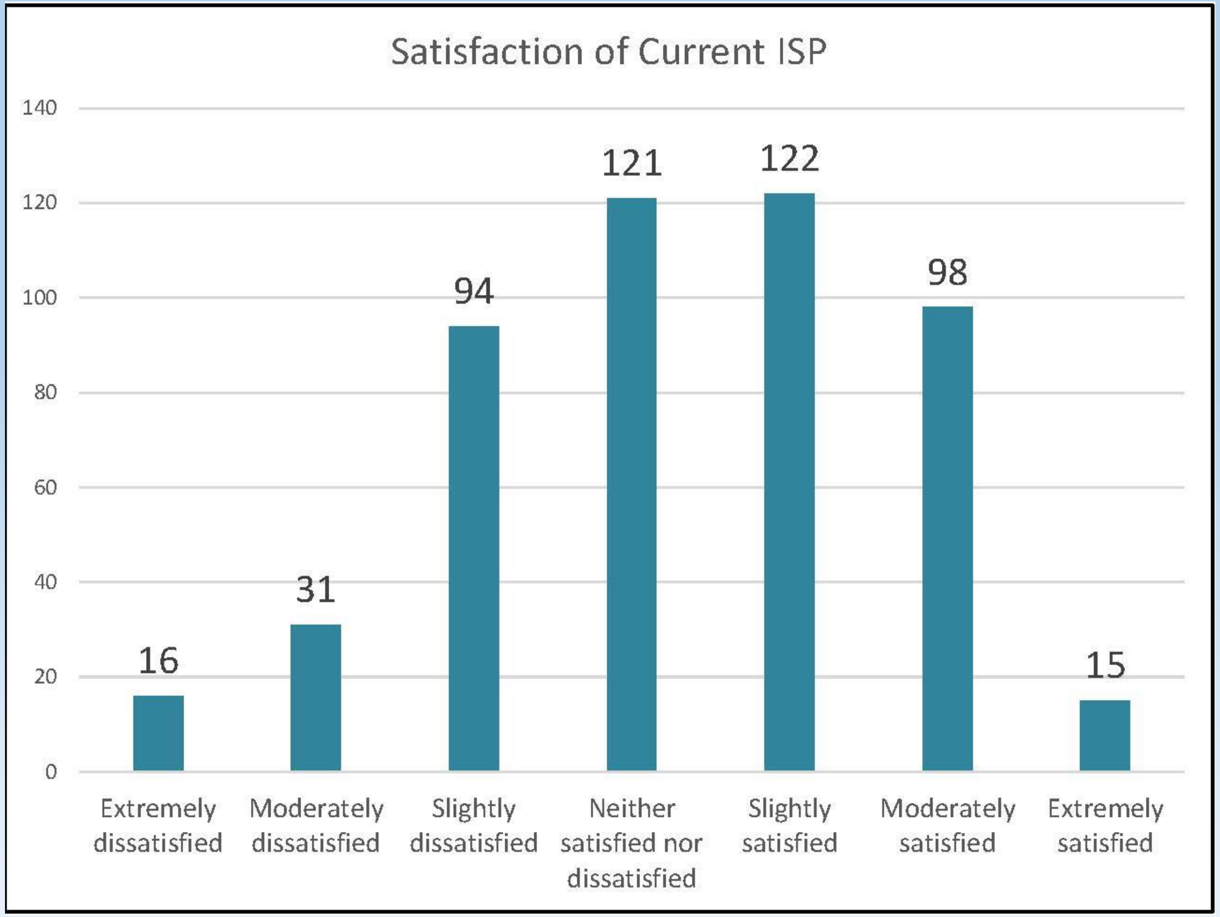
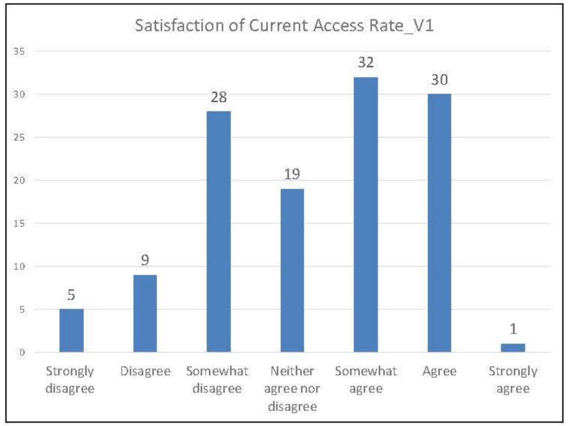
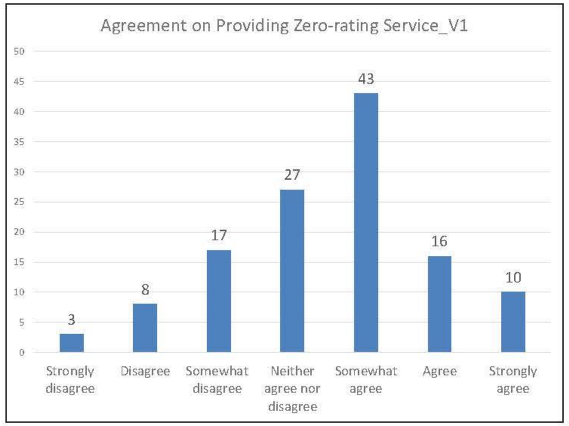
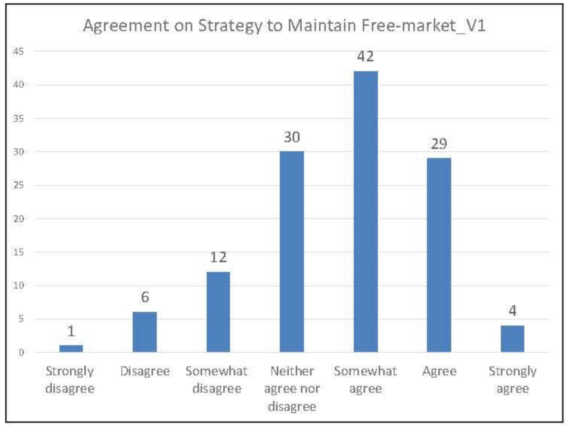
Respondents' satisfaction of current ISP

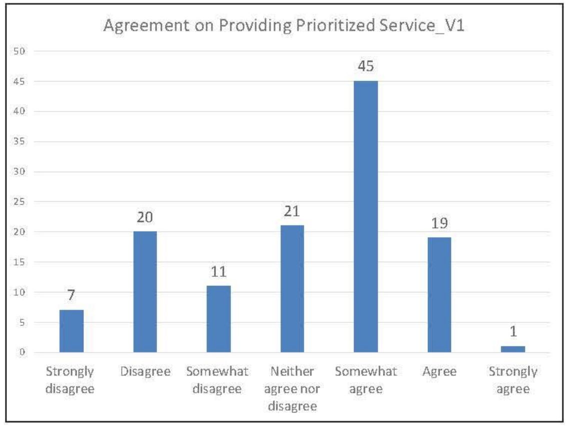


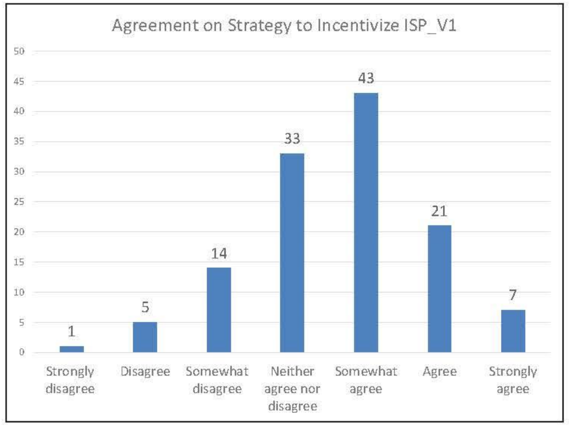
Vignette 1:

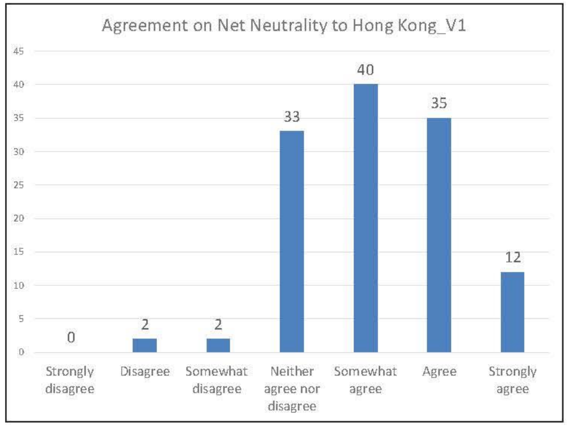

Satisfaction of Current Access Rate_V1
5
9
28
19
32
30
1
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree


Agreement on Providing Zero-rating Service_V1
3
8
17
27
43
16
10
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

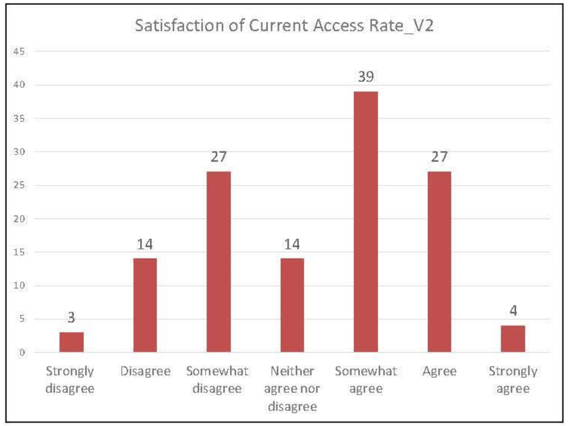

Agreement on Strategy to Maintain Free-market_V1
1
6
12
30
42
29
4
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree


Agreement on Providing Prioritized Service_V1
7
20
11
21
45
19
1
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

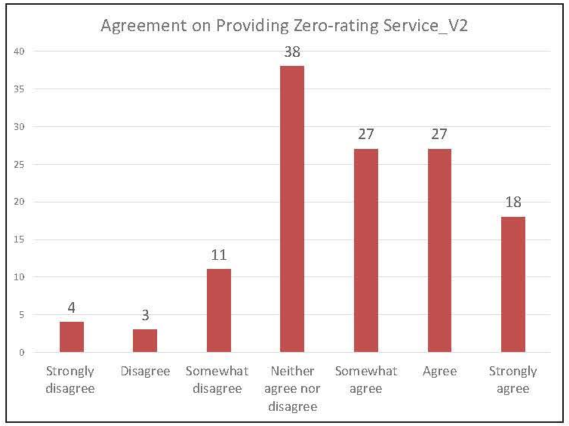

Agreement on Strategy to Incentivize ISP_V1
1
5
14
33
43
21
7
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree


Agreement on Net Neutrality to Hong Kong_V1
0
2
2
33
40
35
12
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

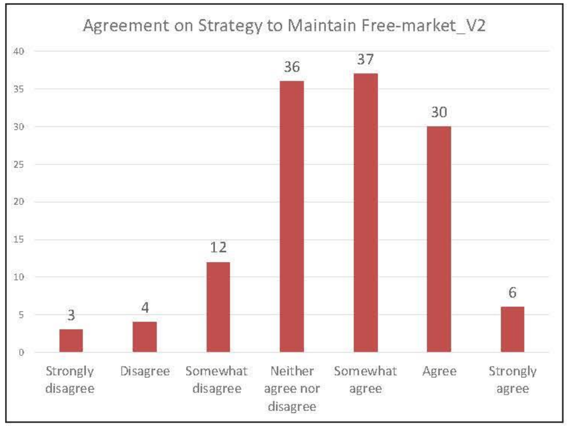
Vignette 2:



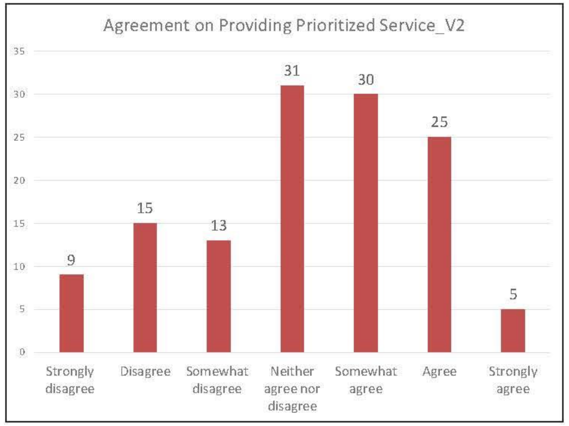
Satisfaction of Current Access Rate_V2
3
14
27
14
39
27
4
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree



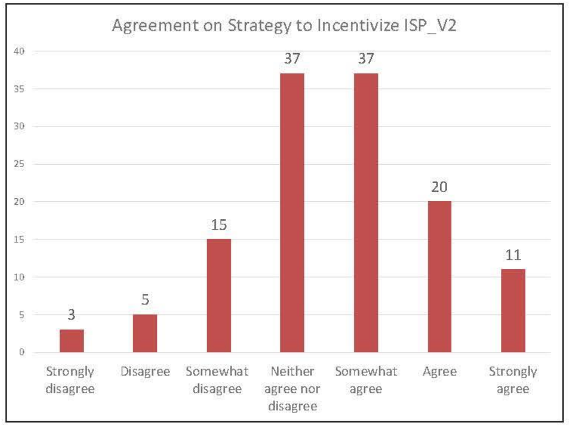
Agreement on Providing Zero-rating Service_V2
4
3
11
38
27
27
18
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree



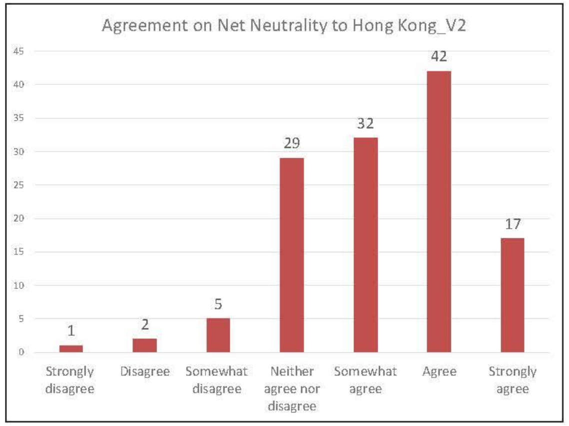
Agreement on Strategy to Maintain Free-market_V2
3
4
12
36
37
30
6
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree



Agreement on Providing Prioritized Service_V2
9
15
13
31
30
25
5
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

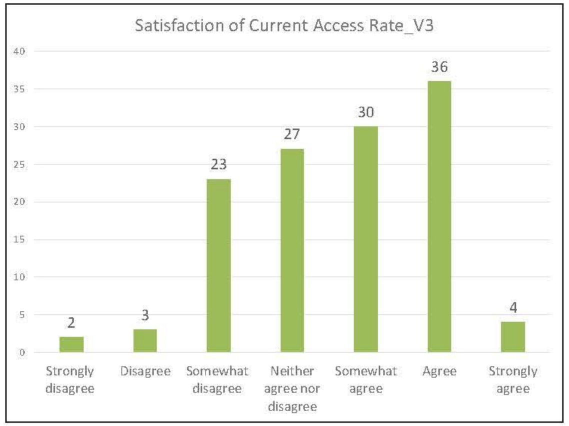


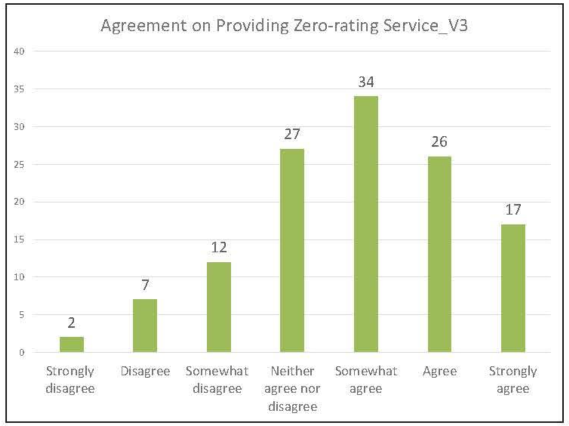
Agreement on Strategy to Incentivize ISP_V2
3
5
15
37
37
20
11
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

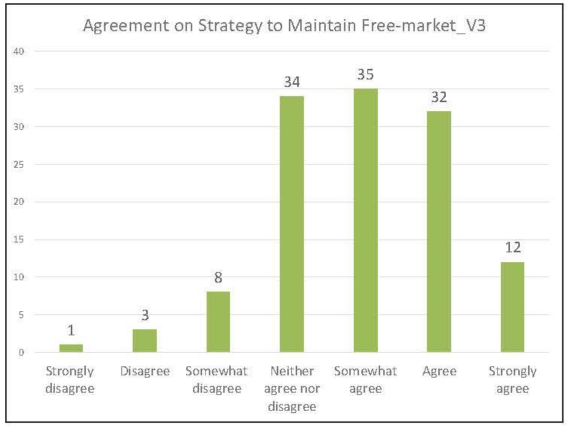


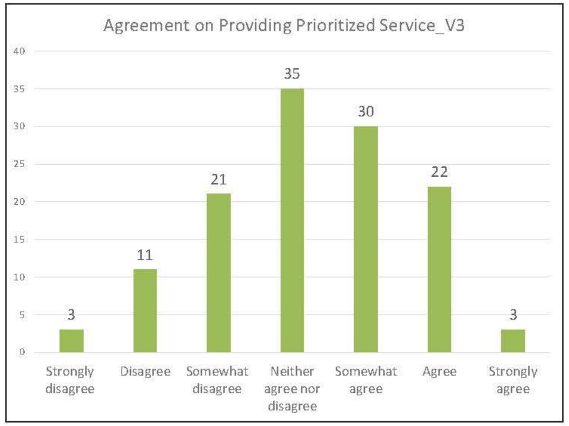
Agreement on Net Neutrality to Hong Kong_V2
1
2
5
29
32
42
17
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

Vignette 3:


Satisfaction of Current Access Rate_V3
0
5
10
15
20
25
30
35
40
2
3
23
27
30
36
4
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree


Agreement on Providing Zero-rating Service_V3
0
5
10
15
20
25
30
35
40
2
7
12
27
34
26
17
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree


Agreement on Strategy to Maintain Free-market_V3
0
5
10
15
20
25
30
35
40
1
3
8
34
35
32
12
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree


Agreement on Providing Prioritized Service_V3
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15
20
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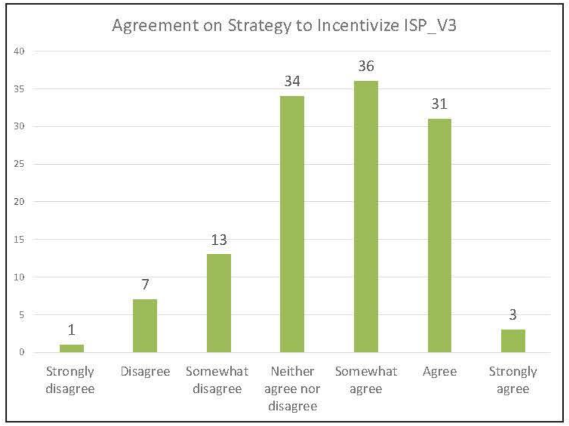
3
11
21
35
30
22
3
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree


Agreement on Strategy to Incentivize ISP_V3
0
5
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15
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35
40
1
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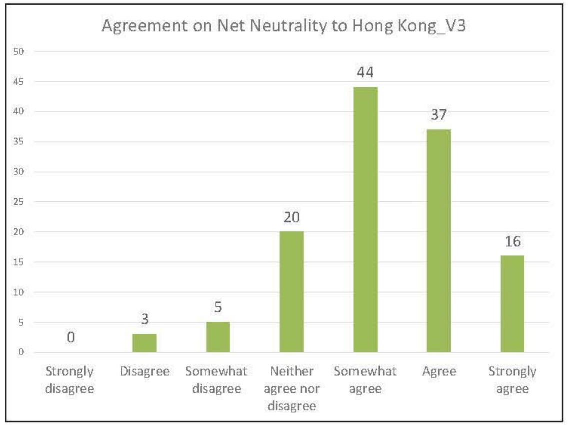
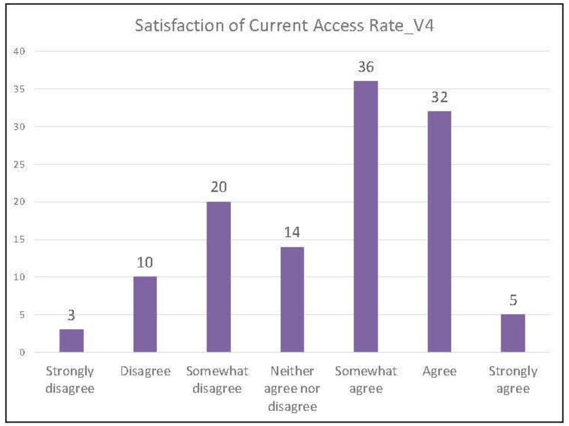
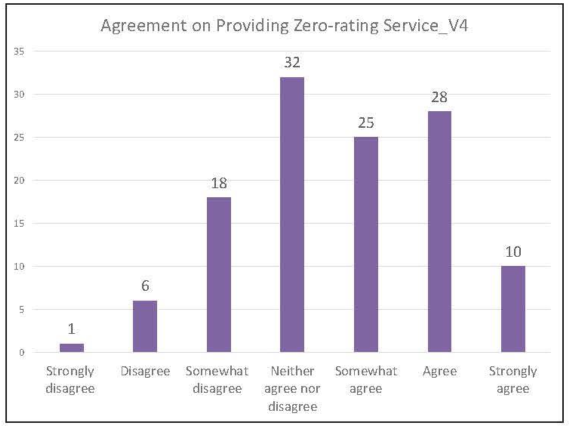
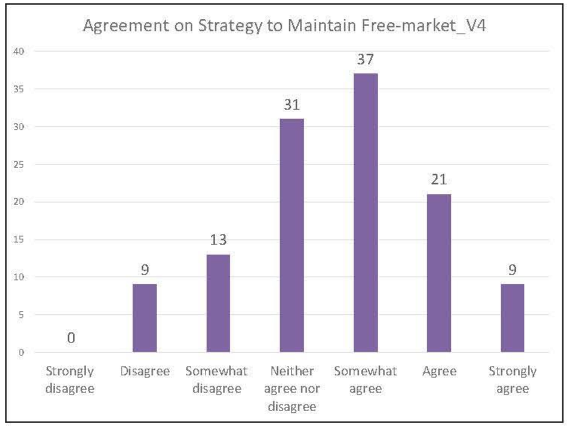
13
34
36
31
3
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

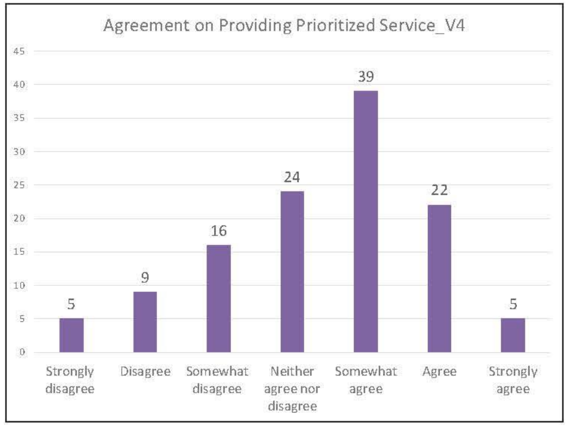

Agreement on Net Neutrality to Hong Kong_V3
0
5
10
15
20
25
30
35
40
45
50
0
3
5
20
44
37
16
Strongly disagree
Disagree
Somewhat disagree
Neither agree nor disagree
Somewhat agree
Agree
Strongly agree

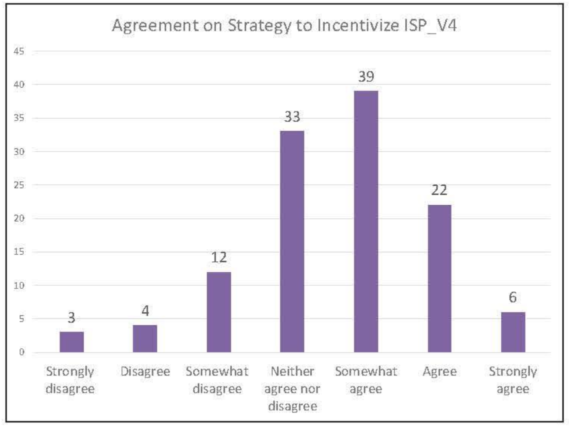
Vignette 4:

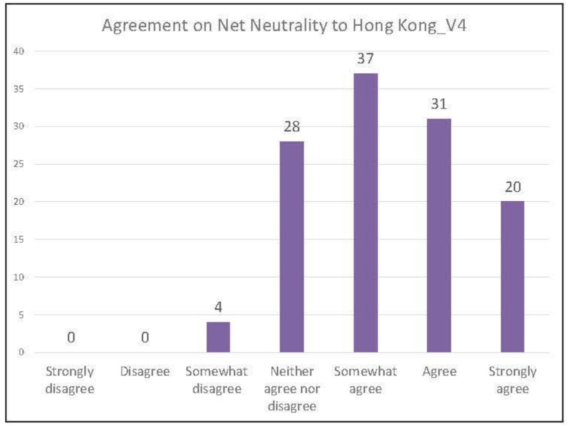












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Thank you!

Q & A