Characterizing Physical-Layer Transmission Errors in Cable Broadband Networks

Jiyao Hu, Zhenyu Zhou, and Xiaowei Yang

Motivation

- Reliable and high-speed Internet access is crucially important

- Quality of broadband networks is of great policy concerns

    - FCC's Measuring Broadband America (MBA) Project

    - Numerous research efforts

Packet Loss Rate is A Network Reliability Indicator

- High packet loss rate harms user's quality of experience

  - \> 1% packet loss -> poor VoIP performance [1]

  - TCP Cubic: > 1% packet loss -> dramatic throughput reduction [2]

[1] FCC. A Report on Consumer Fixed Broadband Performance in the United States. https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-eleventh-report
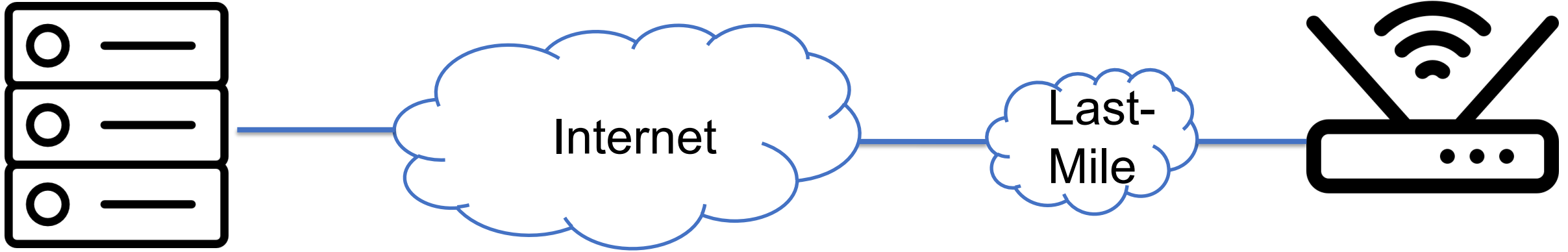
[2] Ha, Sangtae, Injong Rhee, and Lisong Xu. "CUBIC: a new TCP-friendly high-speed TCP variant." ACM SIGOPS operating systems review 42.5 (2008): 64-74.
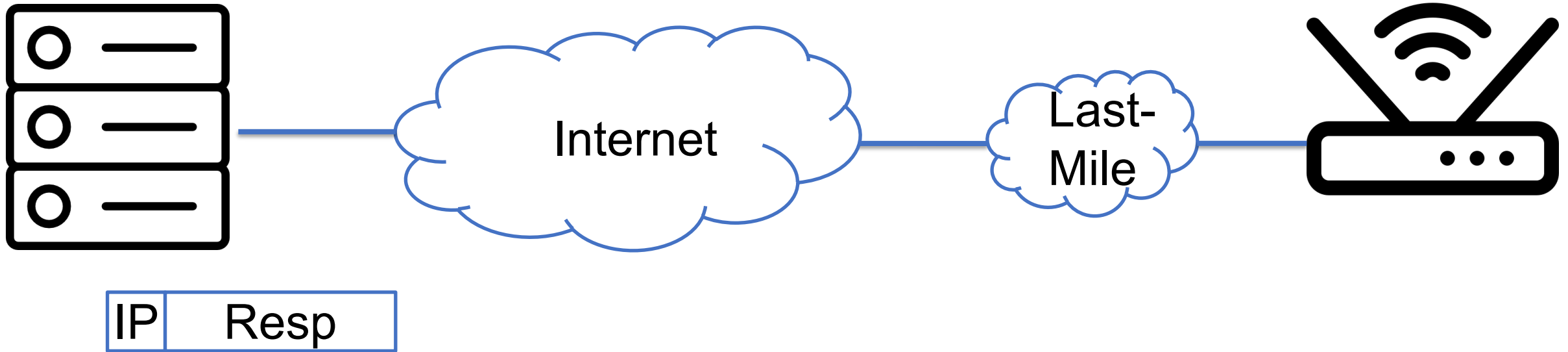
Different Sources of Packet Loss
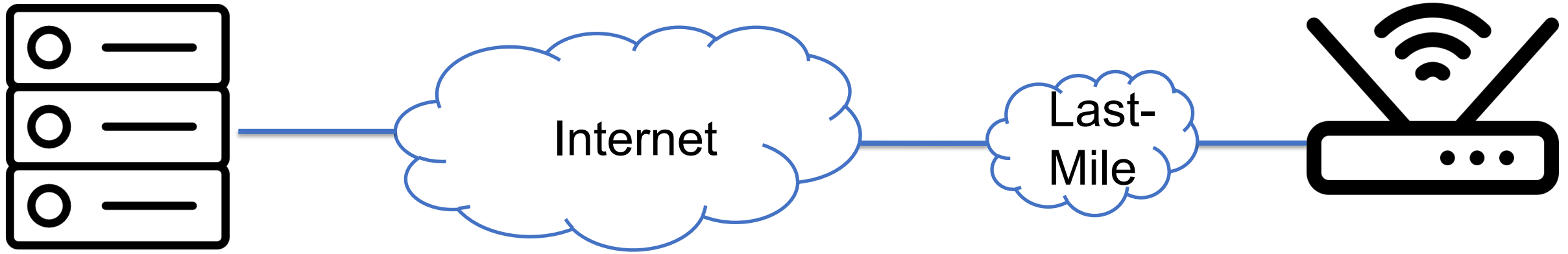
Internet

Last-Mile

Different Sources of Packet Loss

IP	Req

Internet

Last-Mile
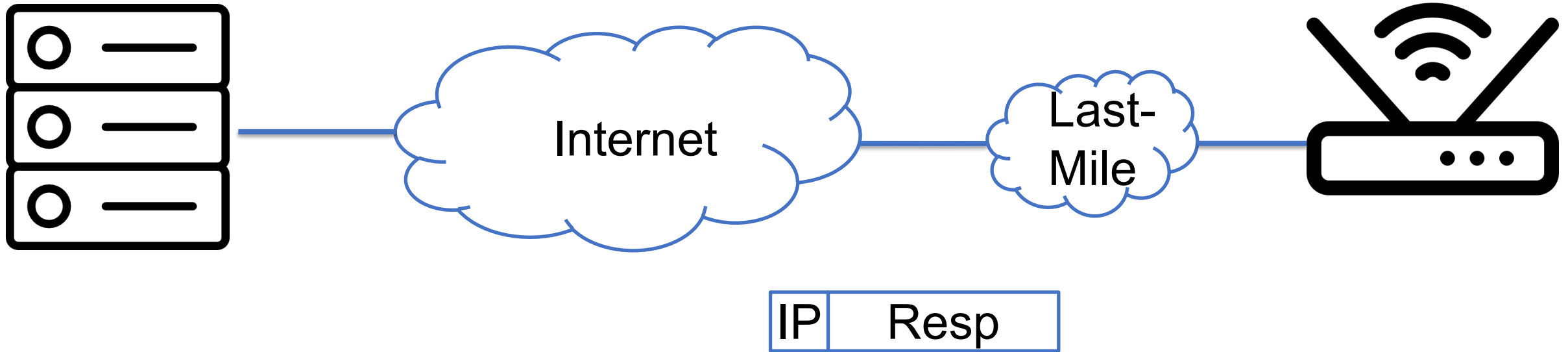
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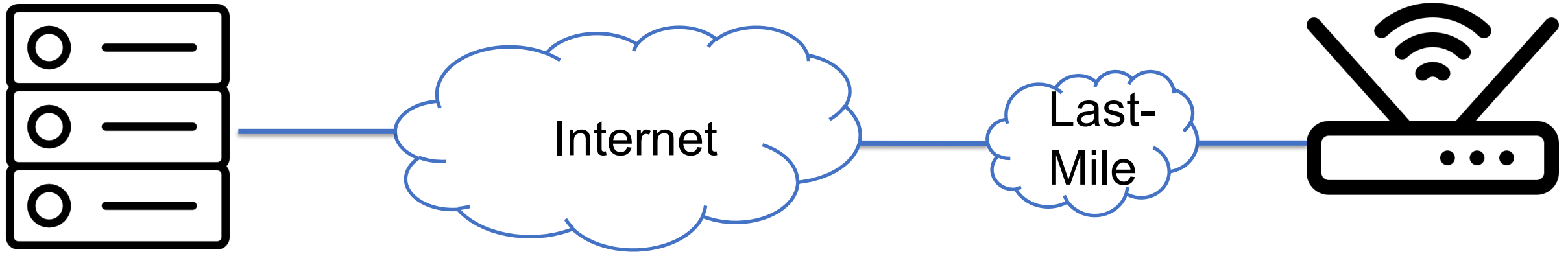| IP	Resp

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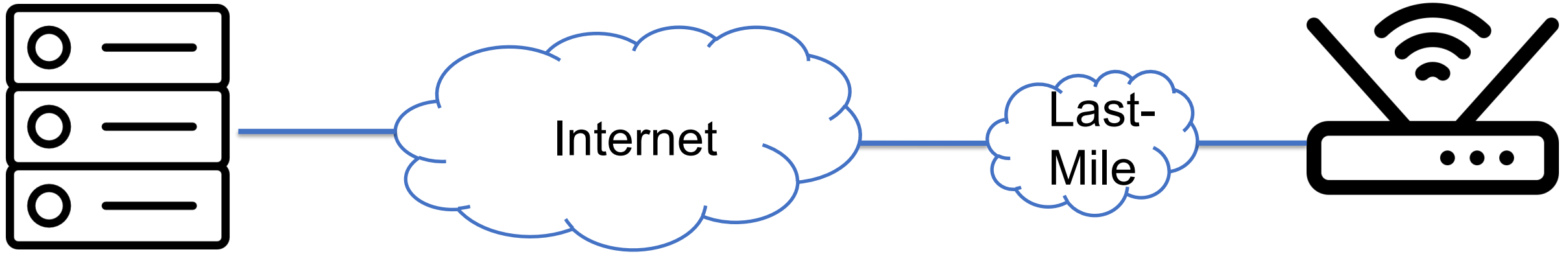
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Internet

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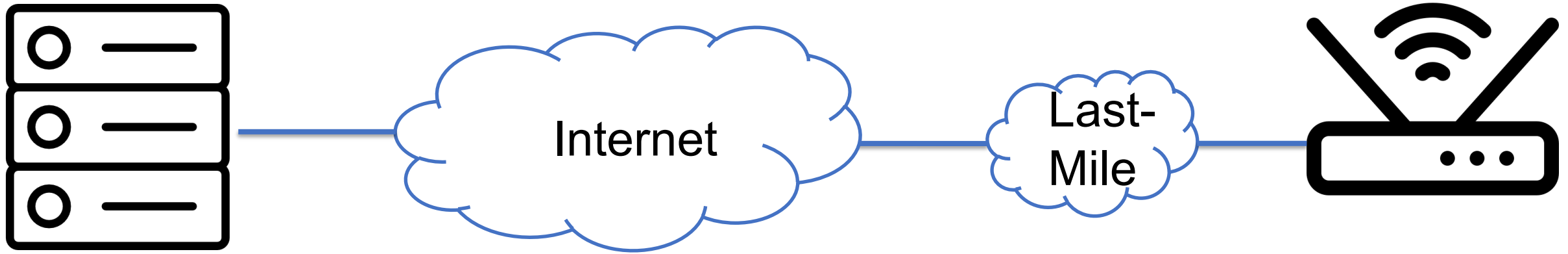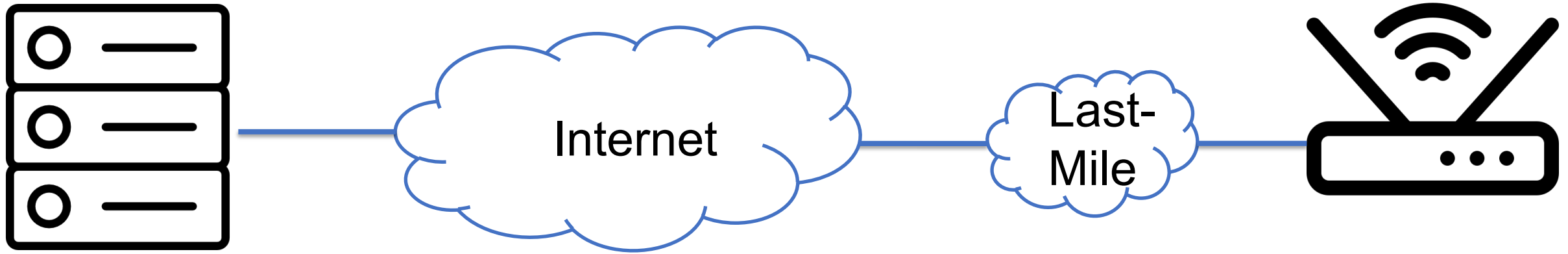- Physical-Layer Transmission Errors -> Network Operating Conditions

Different Sources of Packet Loss

- Physical-Layer Transmission Errors -> Network Operating Conditions
- Network Congestion Loss -> Network Capacity Provisioning

Different Sources of Packet Loss

- Physical-Layer Transmission Errors -> Network Operating Conditions
- Network Congestion Loss -> Network Capacity Provisioning
- Previous work did not distinguish difference sources of packet losses

Importance of Separating Sources of Packet Losses

- Diagnose physical layer infrastructure issues

- Policy interests

- Insight into congestion control and network simulator design

Goals

- Physical-layer transmission errors vs. overall packet losses

- Effects on customer behaviors

- What factors affect physical-layer transmission errors

Roadmap

- Methodology
- Datasets
- Results
  - Overview of physical-layer transmission errors
  - Physical-layer transmission errors vs. overall packet losses
  - Effects on customer behaviors
  - What factors affect physical-layer transmission errors
- Implications & Conclusion

How to Infer Physical-Layer Transmission Errors

Cable Modem Termination System (CMTS)

Fiber

Fiber Optic Node (FN)

Cable

Cable Modem (CM)

How to Infer Physical-Layer Transmission Errors

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How to Infer Physical-Layer Transmission Errors

MAC Frame

Reed-Solomon encoder

Fiber

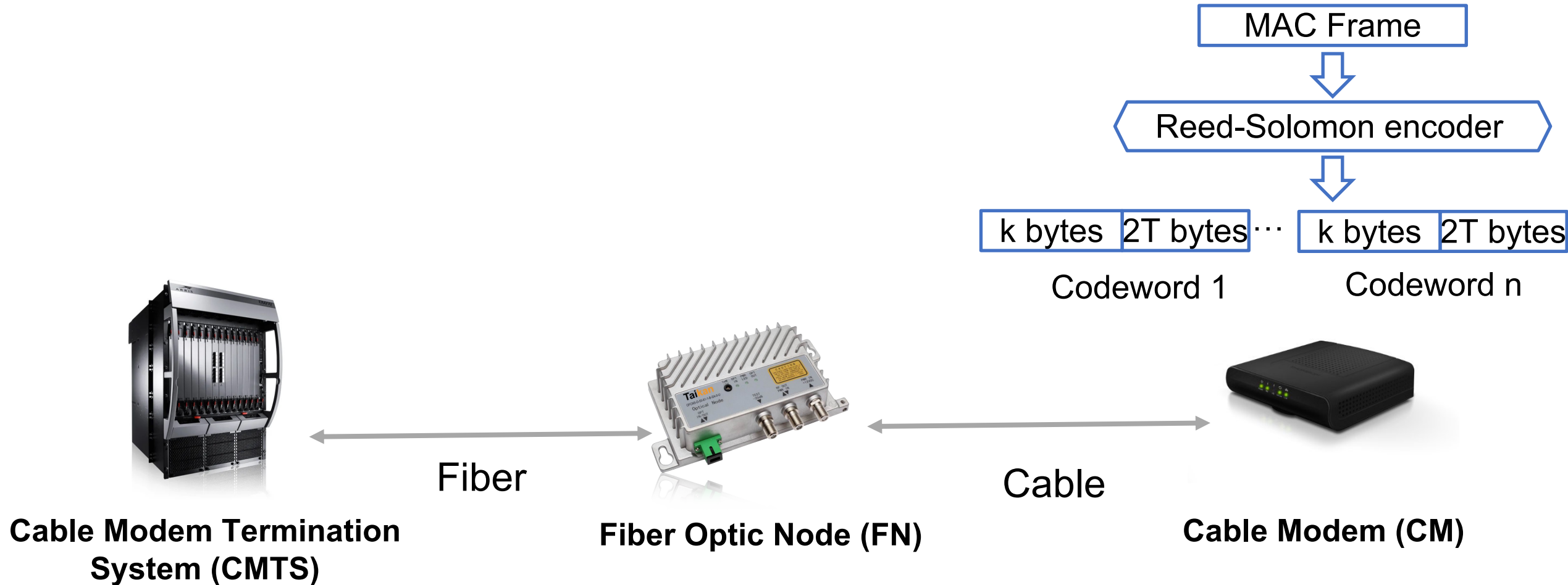Cable

Cable Modem Termination System (CMTS)

Fiber Optic Node (FN)

Cable Modem (CM)

How to Infer Physical-Layer Transmission Errors

MAC Frame

Reed-Solomon encoder

| k bytes | 2T bytes | ⋯ | k bytes | 2T bytes |

Codeword 1　　　　Codeword n

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Fiber

Fiber Optic Node (FN)

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Cable Modem (CM)

How to Infer Physical-Layer Transmission Errors

MAC Frame

Reed-Solomon encoder

k bytes | 2T bytes $\cdots$ k bytes | 2T bytes

Codeword 1   Codeword n

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How to Infer Physical-Layer Transmission Errors

Types of Codewords

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How to Infer Physical-Layer Transmission Errors

Types of Codewords
- Unerrored Codewords

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How to Infer Physical-Layer Transmission Errors

Types of Codewords
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Codeword Error Rate =

How to Infer Physical-Layer Transmission Errors

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Codeword Error Rate = $\dfrac{\text{\# of uncorrectable codewords}}{\text{\# of all codewords}}$

Codeword Details

Codeword Details

Long Codeword

200 bytes	2*15 bytes

Codeword Details

Long Codeword	

200 bytes	2*15 bytes

Long Codeword

99 bytes	2*5 bytes

Short Codeword

Codeword Details

Long Codeword	200 bytes	2*15 bytes

Short Codeword	99 bytes	2*5 bytes

Long Error Rate ≤ Avg Error Rate ≤ Short Error Rate

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Datasets

- Proactive Network Maintenance (PNM) dataset and trouble tickets

- FCC dataset: Measuring Broadband America Project

- AnonISP dataset: IP layer packet loss in our cooperating ISP

PNM Data Collection Infra

Fiber

Cable

Cable Modem Termination System (CMTS)

Fiber Optic Node (FN)
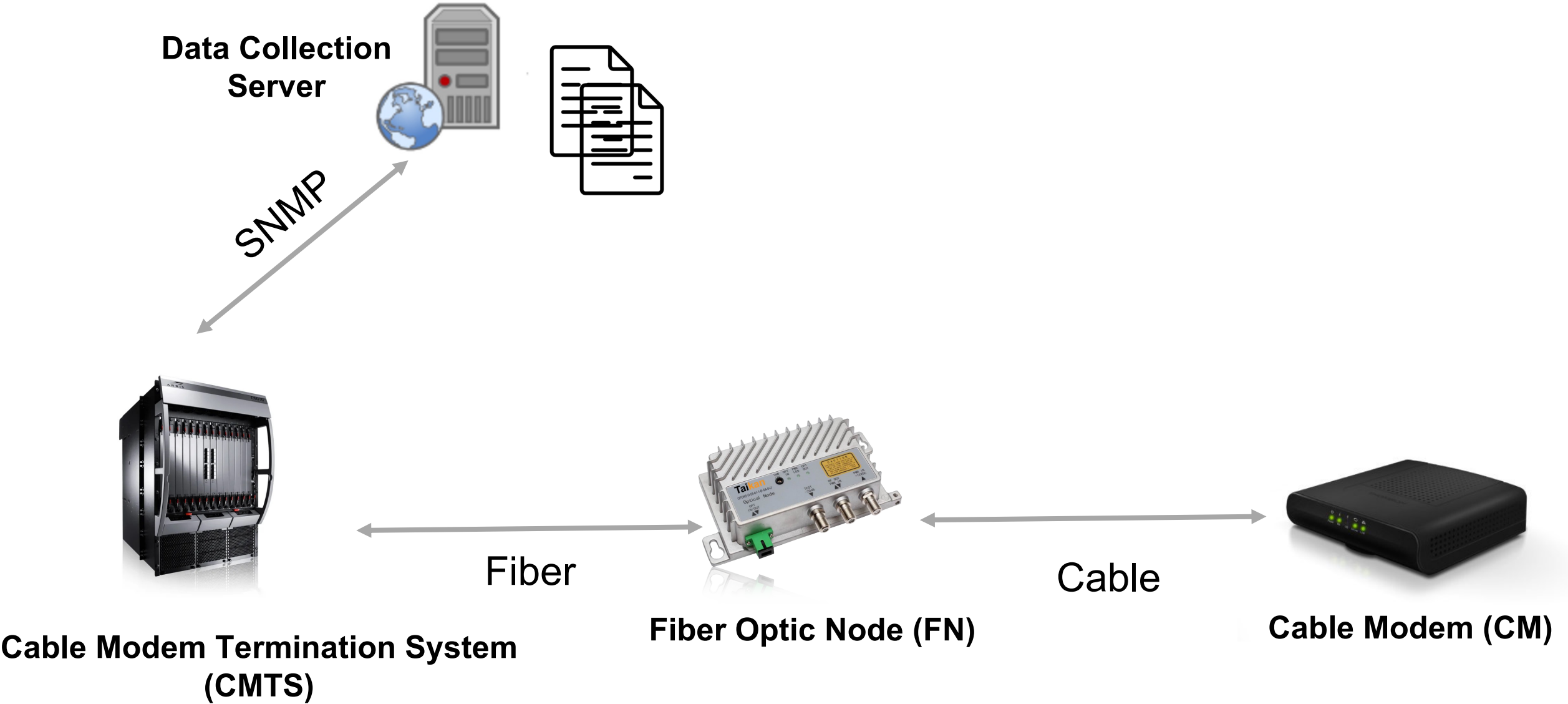
Cable Modem (CM)

PNM Data Collection Infra

Data Collection Server

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PNM Data Collection Infra

Data Collection
Server

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Cable Modem (CM)

PNM Data Collection Infra

Data Collection Server

SNMP

Cable Modem Termination System (CMTS)

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Fiber Optic Node (FN)

Cable

Cable Modem (CM)

PNM Data Collection Infra

Data Collection Server

SNMP
~ 4 hours

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PNM Data Collection Infra

Data Collection Server

SNMP ~ 4 hours

Cable Modem Termination System (CMTS)

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Fiber Optic Node (FN)

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Cable Modem (CM)

PNM Data Collection Infra

Data Collection Server

Transmission Power

SNMP

~ 4 hours

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Data Collection Server

Transmission Power
Signal-to-Noise Ratio (SNR)

SNMP
~ 4 hours

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PNM Data Collection Infra

Transmission Power
Signal-to-Noise Ratio (SNR)
# of Correctable Codewords

Data Collection Server

SNMP
~ 4 hours

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Transmission Power
Signal-to-Noise Ratio (SNR)
# of Correctable Codewords
# of Uncorrectable Codewords

SNMP
~ 4 hours

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SNMP

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Transmission Power
Signal-to-Noise Ratio (SNR)
# of Correctable Codewords
# of Uncorrectable Codewords
# of Unerrored Codewords
...

Fiber

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**Cable Modem Termination System
(CMTS)**

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PNM Data Collection Infra

Data Collection Server

Transmission Power
Signal-to-Noise Ratio (SNR)
# of Correctable Codewords
# of Uncorrectable Codewords
# of Unerrored Codewords
...   Only from Upstream

SNMP
~ 4 hours

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Signal-to-Noise Ratio (SNR)
# of Correctable Codewords
# of Uncorrectable Codewords
# of Unerrored Codewords
… Only from Upstream

SNMP ~ 4 hours

TICKET

Fiber

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PNM Data Collection Infra

Data Collection Server

Transmission Power
Signal-to-Noise Ratio (SNR)
# of Correctable Codewords
# of Uncorrectable Codewords
# of Unerrored Codewords
...   Only from Upstream

SNMP
~ 4 hours

Report Time
Description
Action
...

TICKET

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Datasets

- Proactive Network Maintenance (PNM) dataset and trouble tickets
  - Collected from 01/06/2019 to 04/17/2020
  - 398M data points among 77k devices from 394 FNs, 15k trouble tickets

- FCC dataset: Measuring Broadband America Project
  - Collected from the same period as PNM data
  - 19M data points among 1k cable devices from 5 cable ISPs

- AnonISP dataset: Similar measurement as FCC data on our cable network
  - Collected from 11/03/2021 to 11/11/2021
  - 3M data points among 19k devices

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Complementary CDF of Codeword Error Rate

Complementary CDF of Codeword Error Rate

- 21.5MHz Channel —
- 28.4MHz Channel – – –
- 35.3MHz Channel ·····
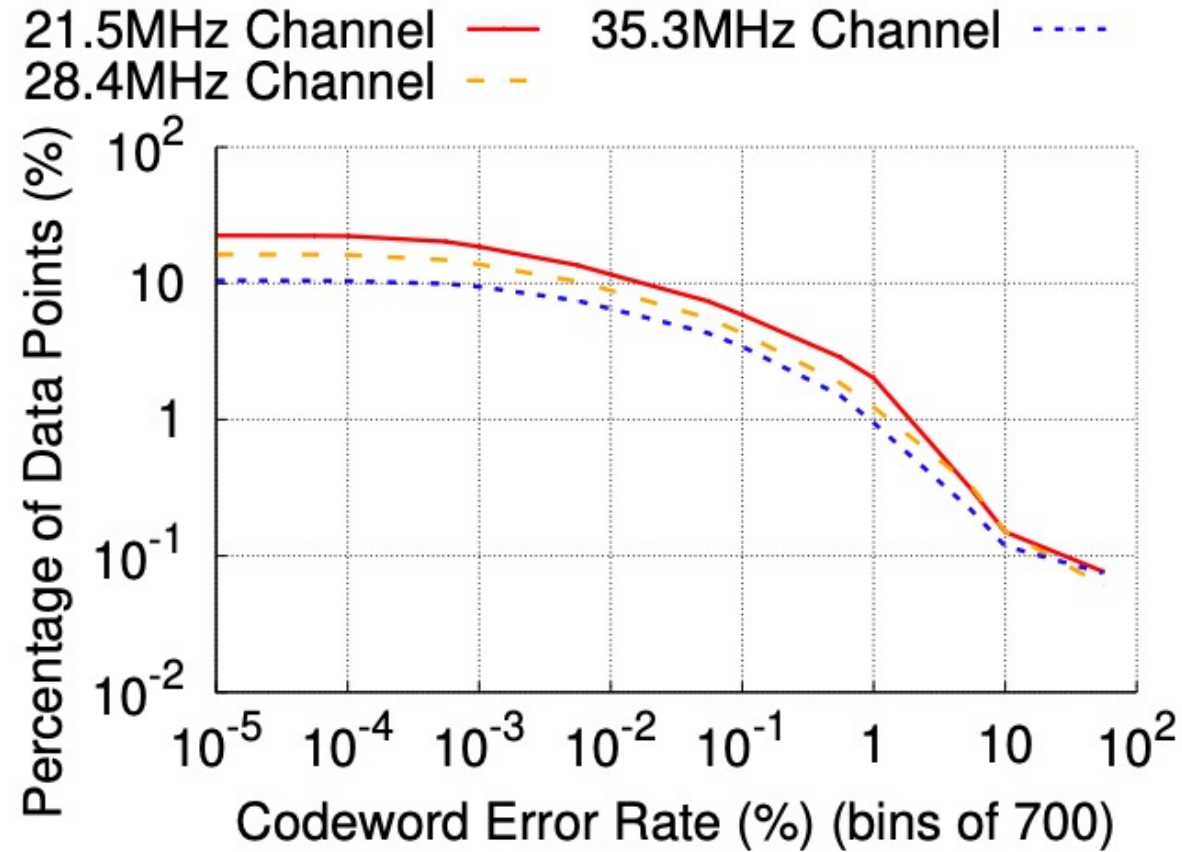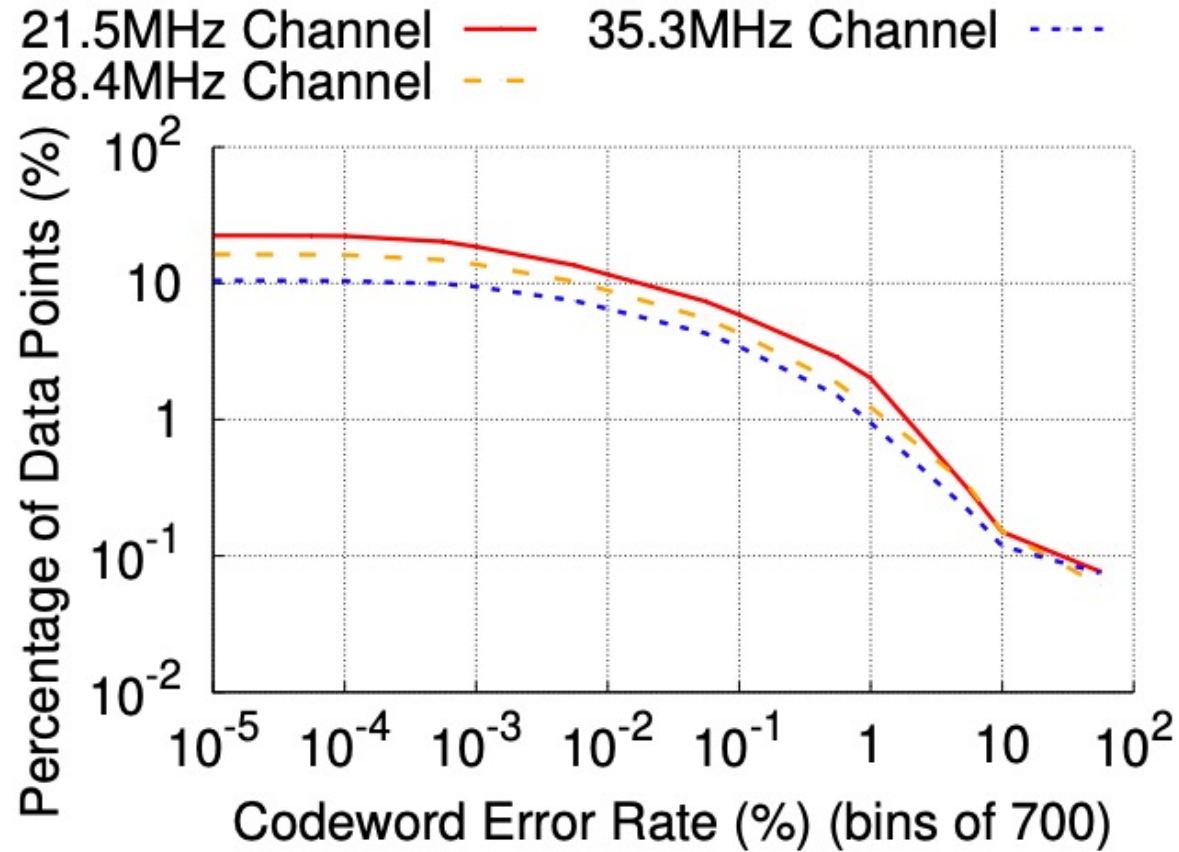
•Error rate = $\dfrac{\text{\# of uncorrectable}}{\text{\# of all types}}$

Complementary CDF of Codeword Error Rate
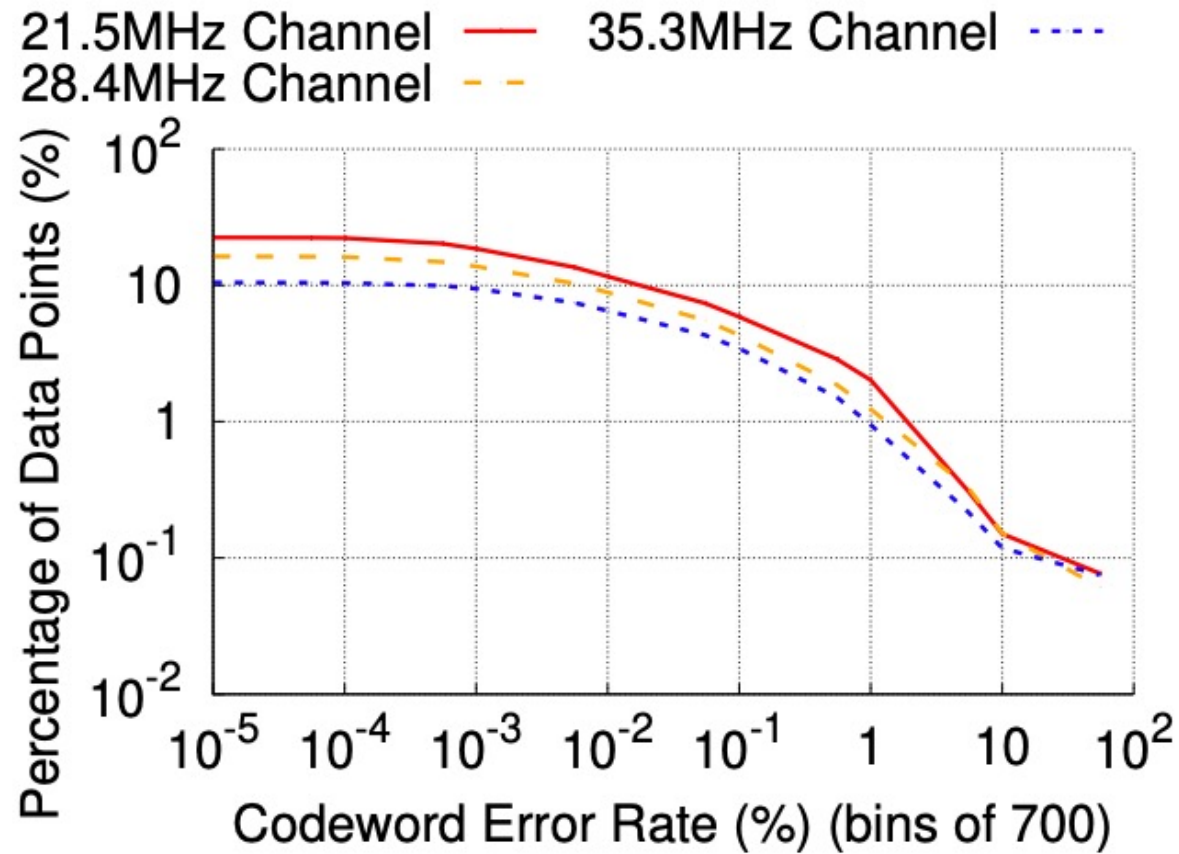
21.5MHz Channel —— 35.3MHz Channel ----
28.4MHz Channel — —

•Error rate = $\dfrac{\text{\# of uncorrectable}}{\text{\# of all types}}$

•Higher frequency -> lower codeword error rate

Complementary CDF of Codeword Error Rate
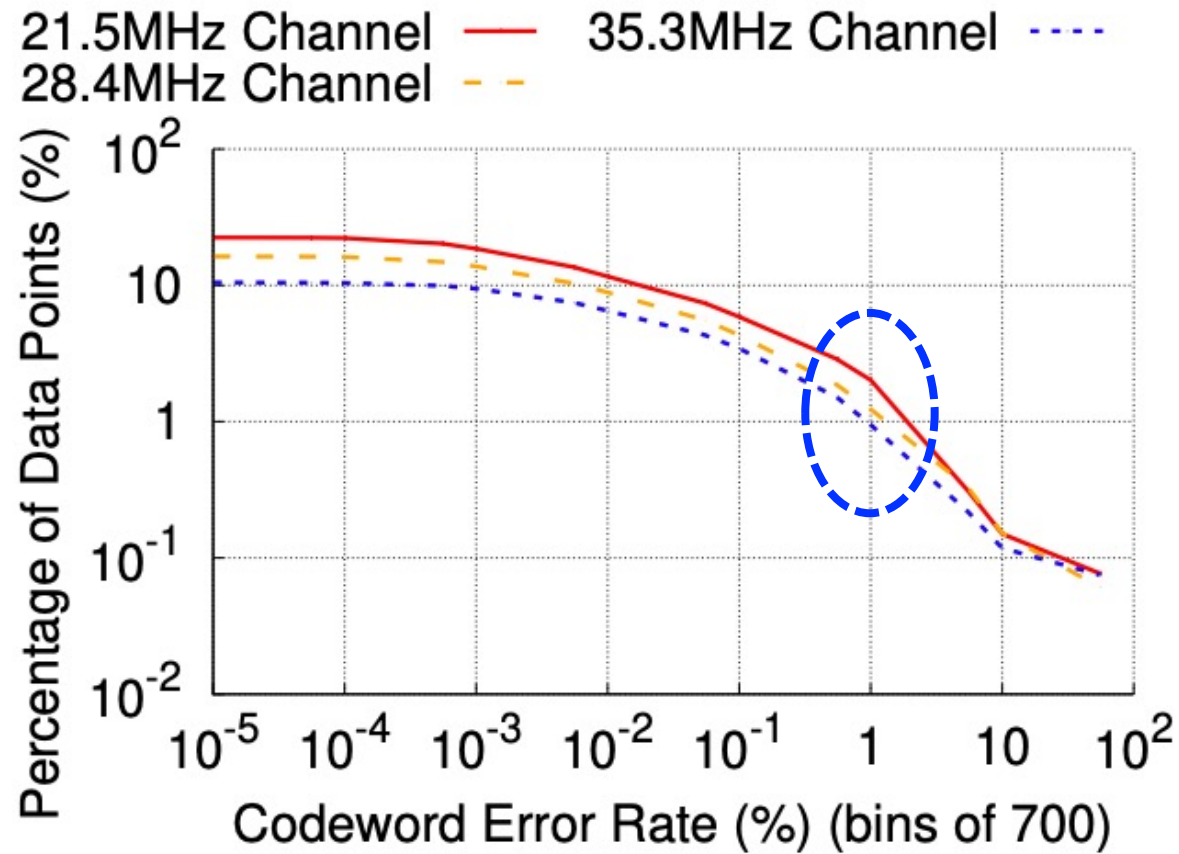
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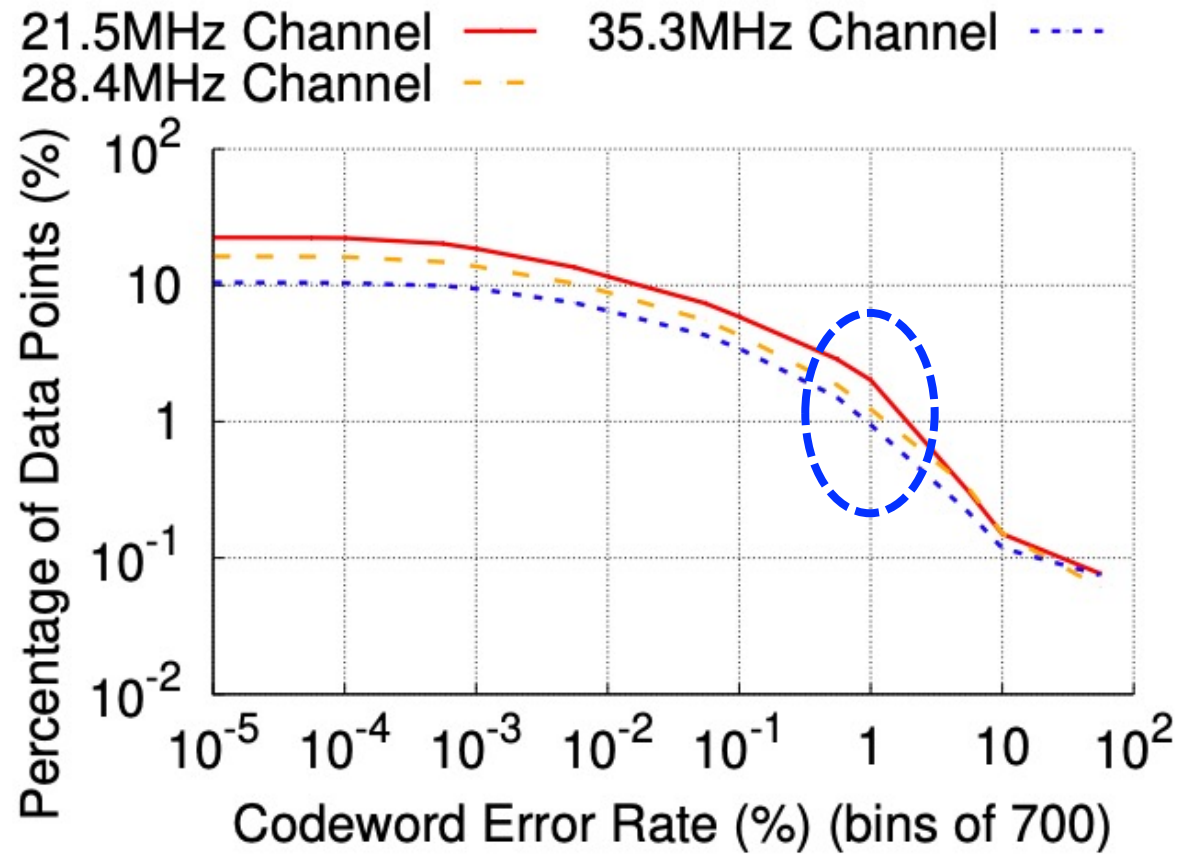
- Error rate = $\dfrac{\text{\# of uncorrectable}}{\text{\# of all types}}$

- Higher frequency -> lower codeword error rate

- ~ 1% of data have codeword error rate > 1%

Complementary CDF of Codeword Error Rate
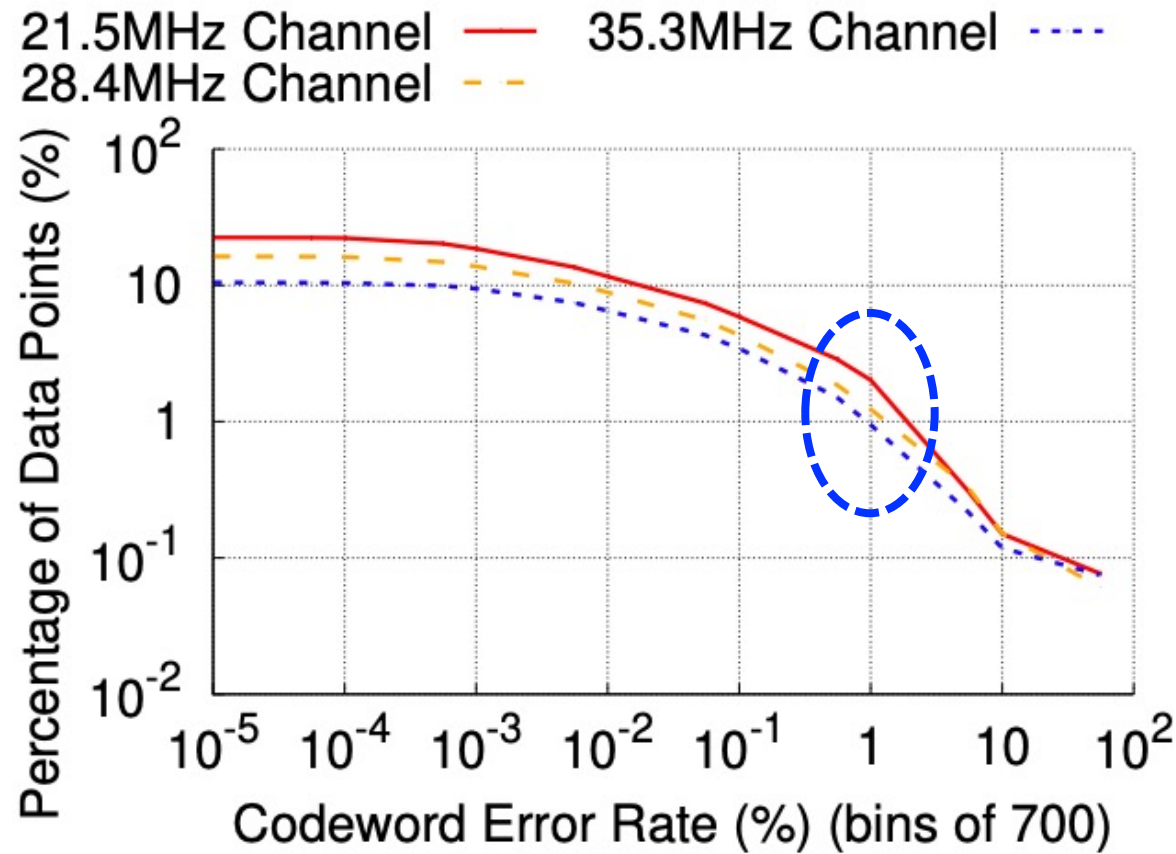
- Error rate = $\dfrac{\text{\# of uncorrectable}}{\text{\# of all types}}$

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- ~ 1% of data have codeword error rate > 1%

- Combined 3 channels for later analysis

Codeword Error Rate in Different FNs
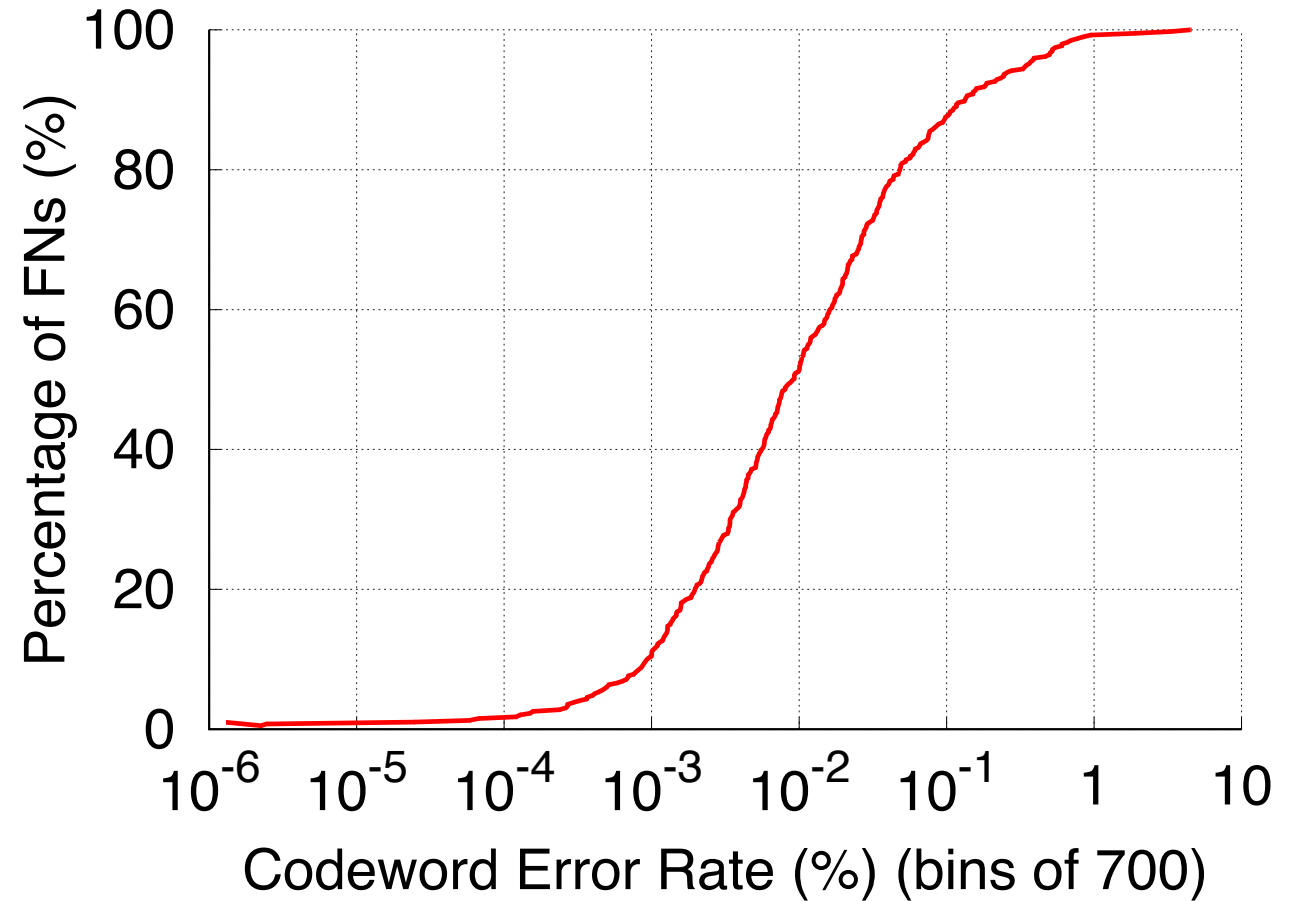
Codeword Error Rate in Different FNs

1% Unhealthy FNs

Percentage of FNs (%)

Codeword Error Rate (%) (bins of 700)

Codeword Error Rate in Different FNs

1% Unhealthy FNs

12% Alarming FNs

Codeword Error Rate in Different FNs

Codeword Error Rate in Different FNs

1% Unhealthy FNs

12% Alarming FNs
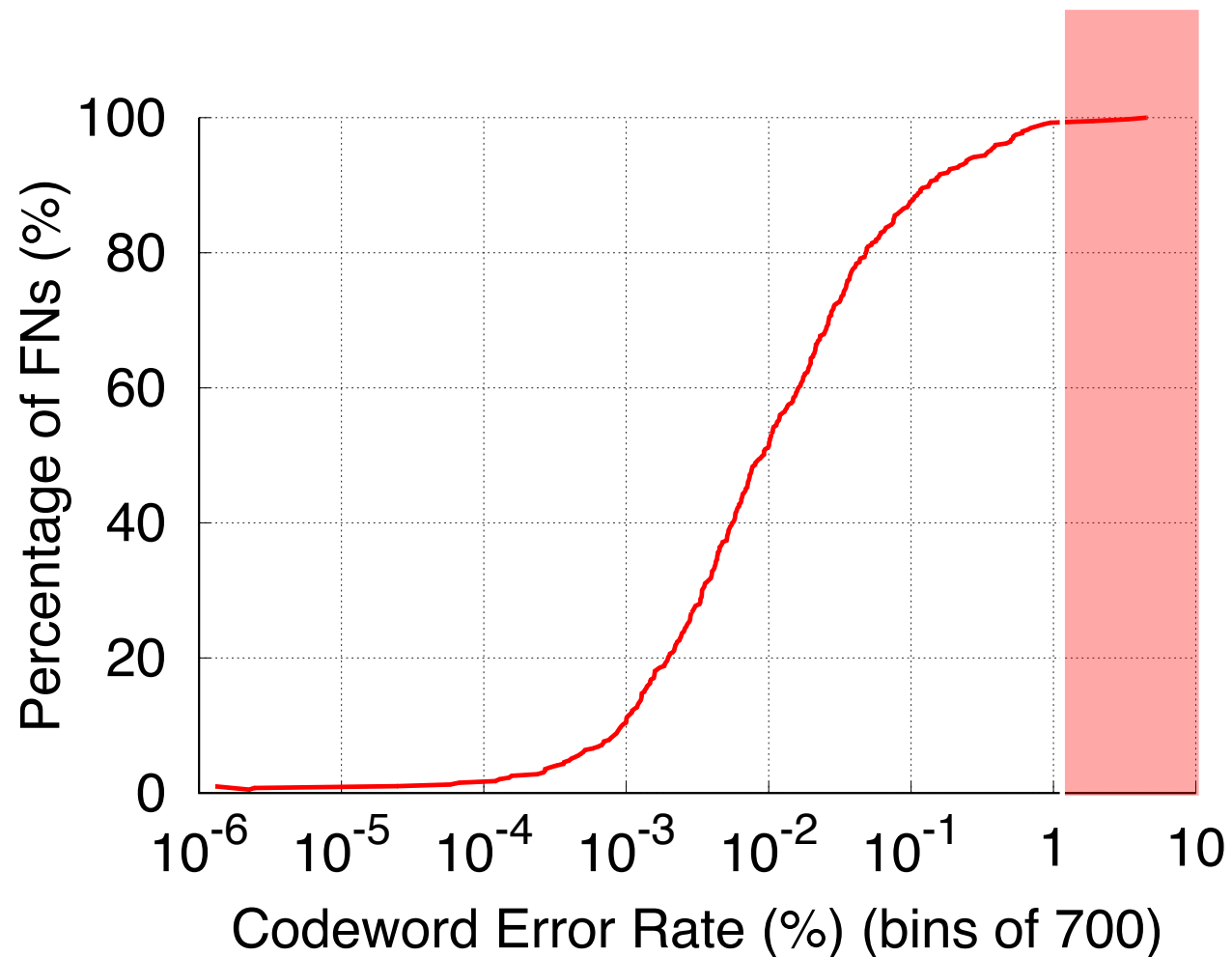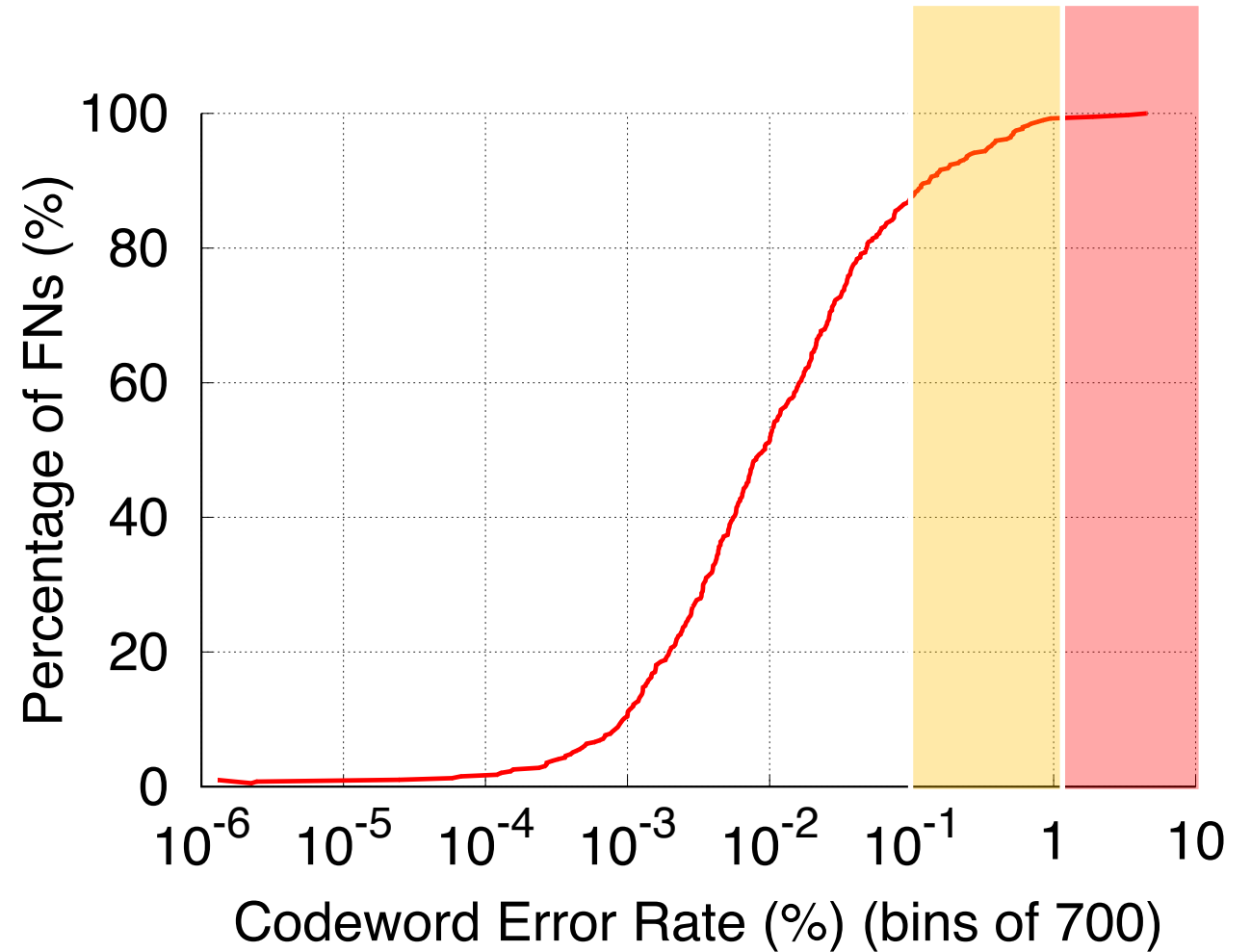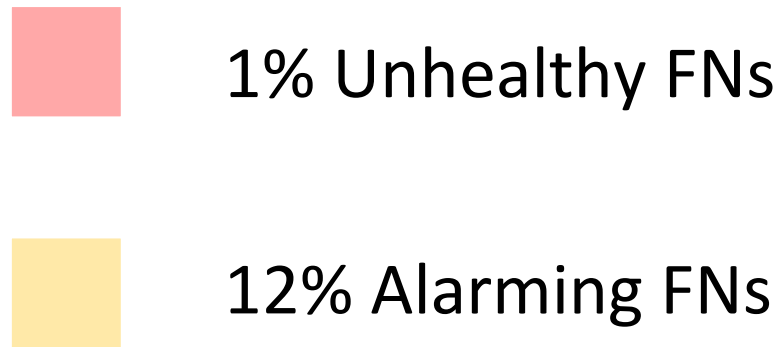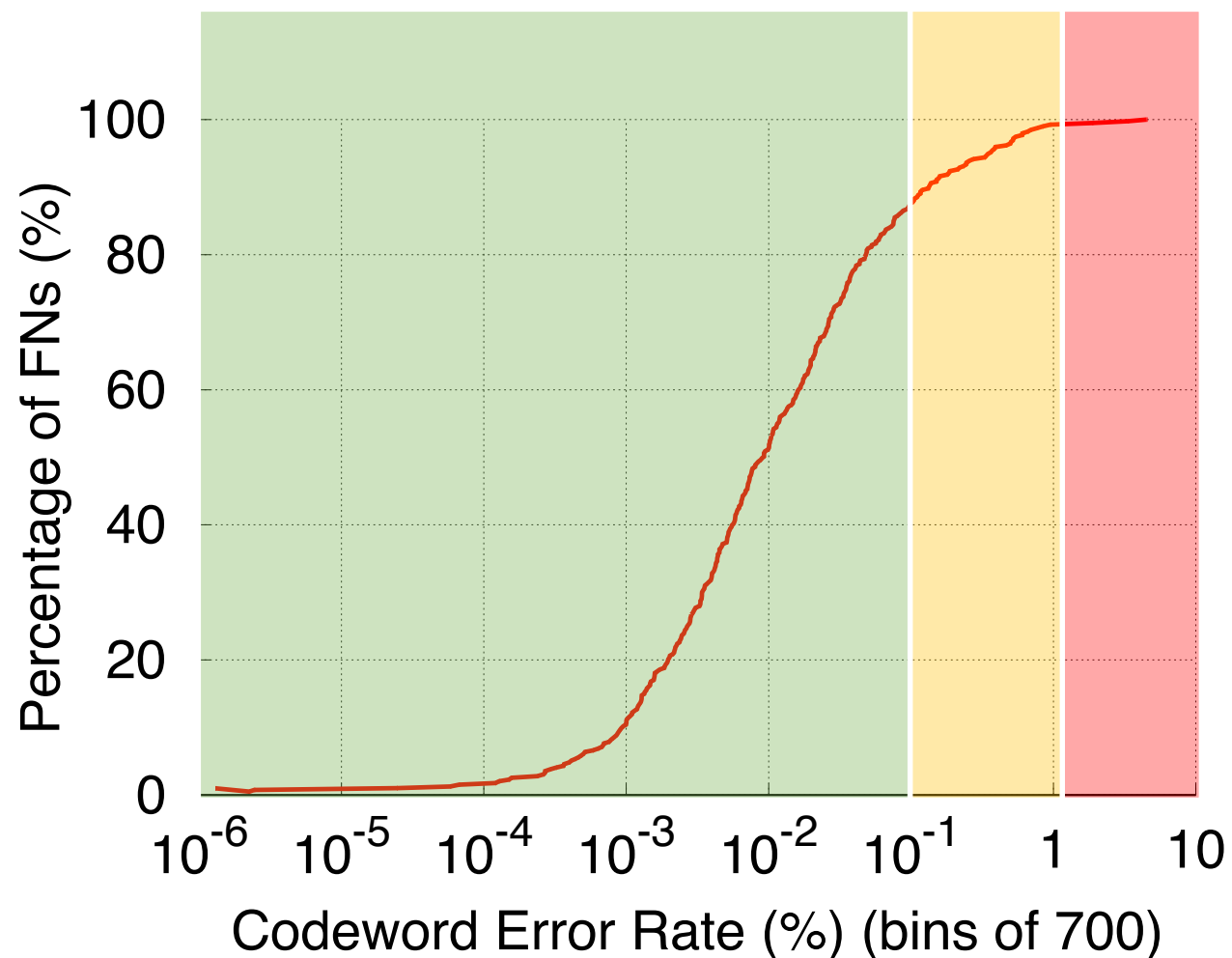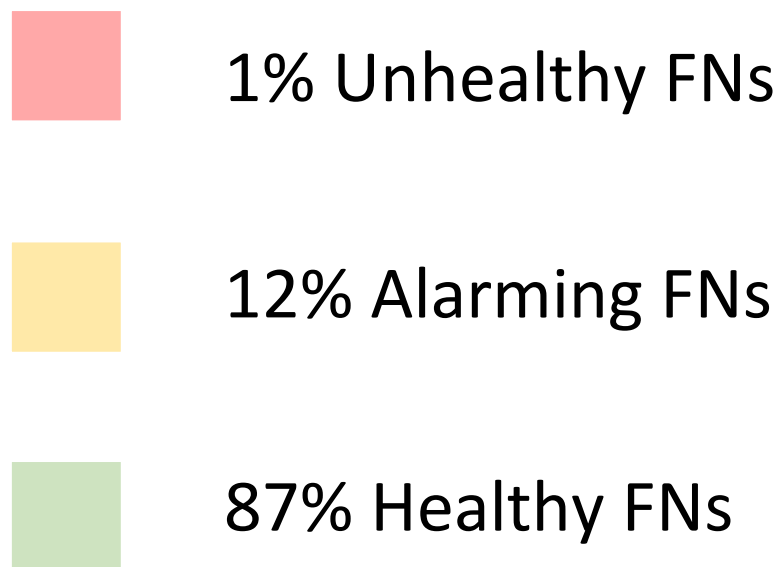
87% Healthy FNs
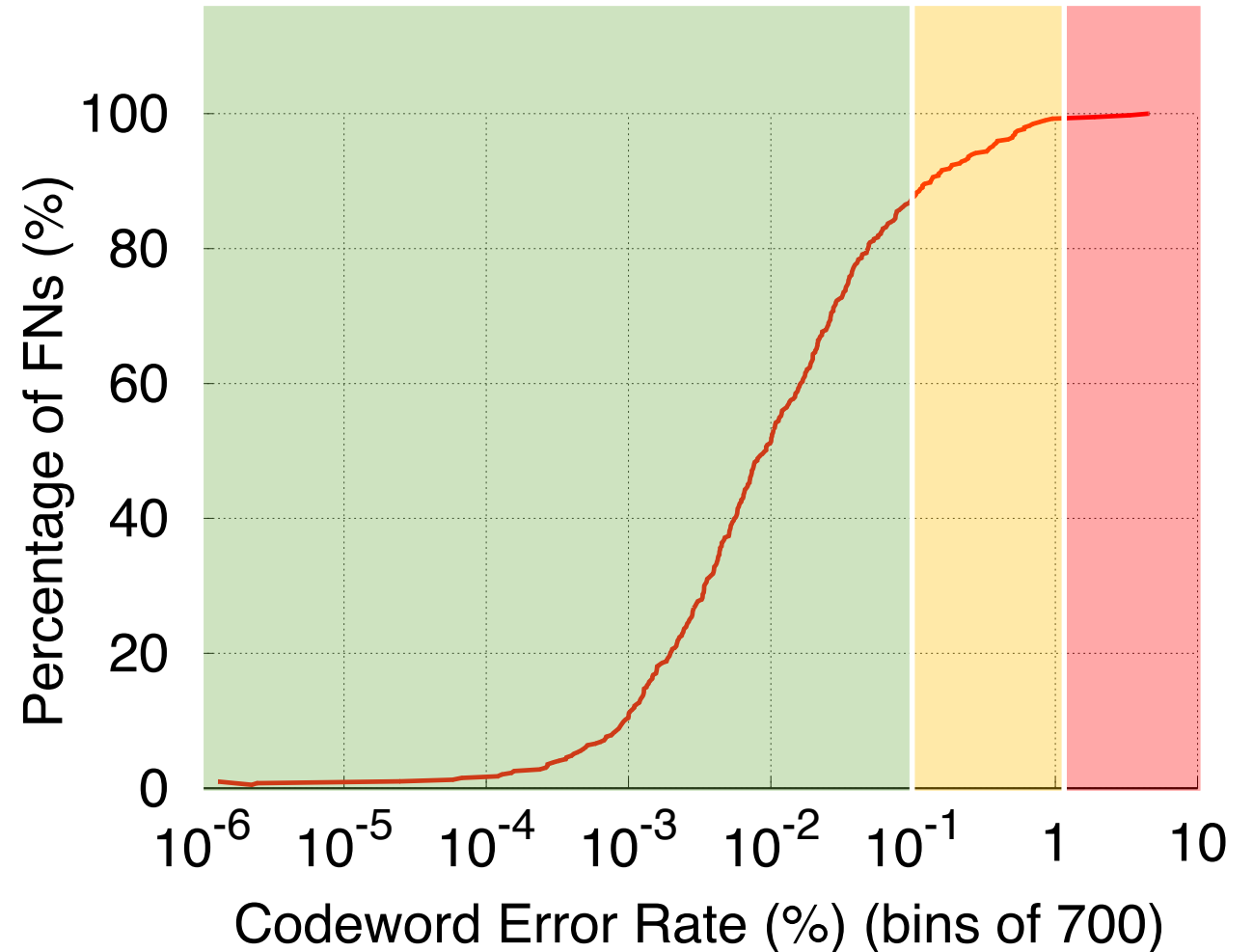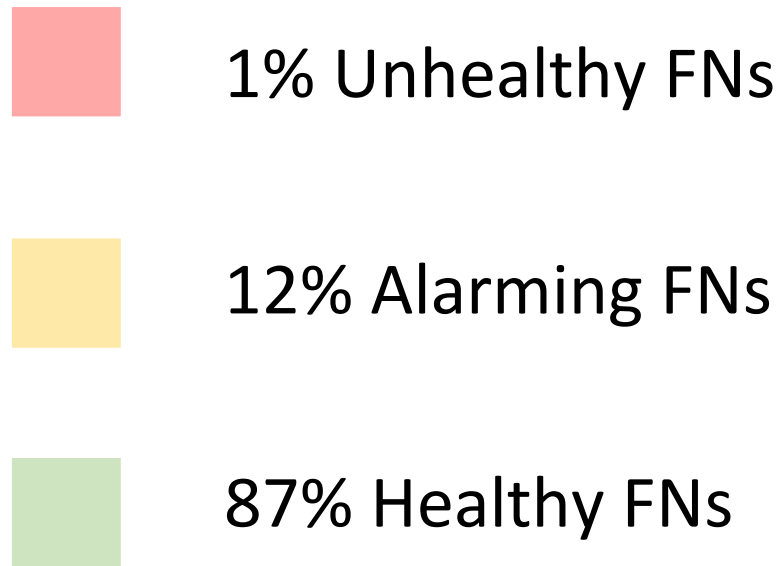
Wired networks can suffer high physical-layer packet loss rates

An Example of An Abnormal FN
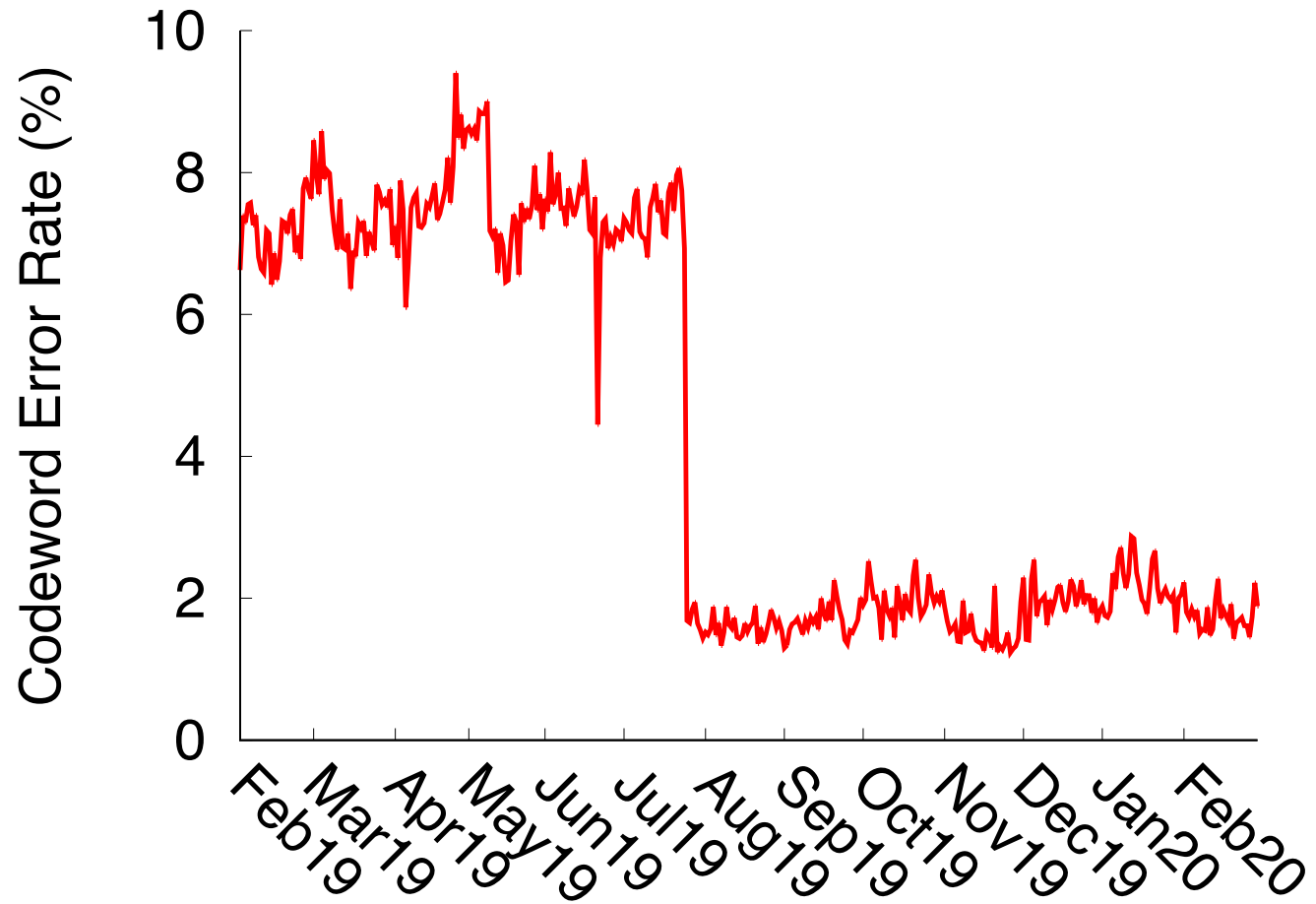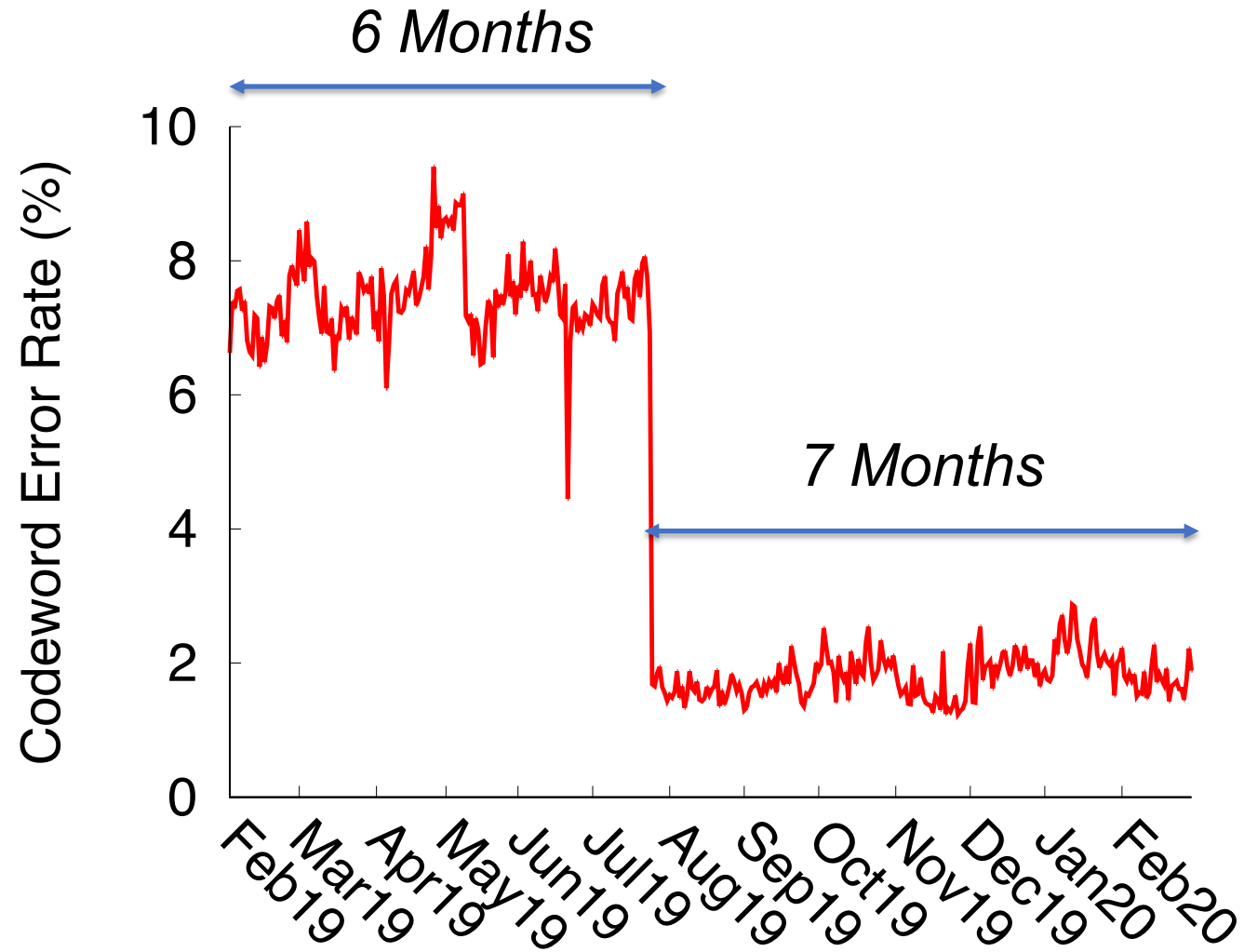
An Example of An Abnormal FN

An Example of An Abnormal FN

Roadmap

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IP-layer Packet Loss Statistics
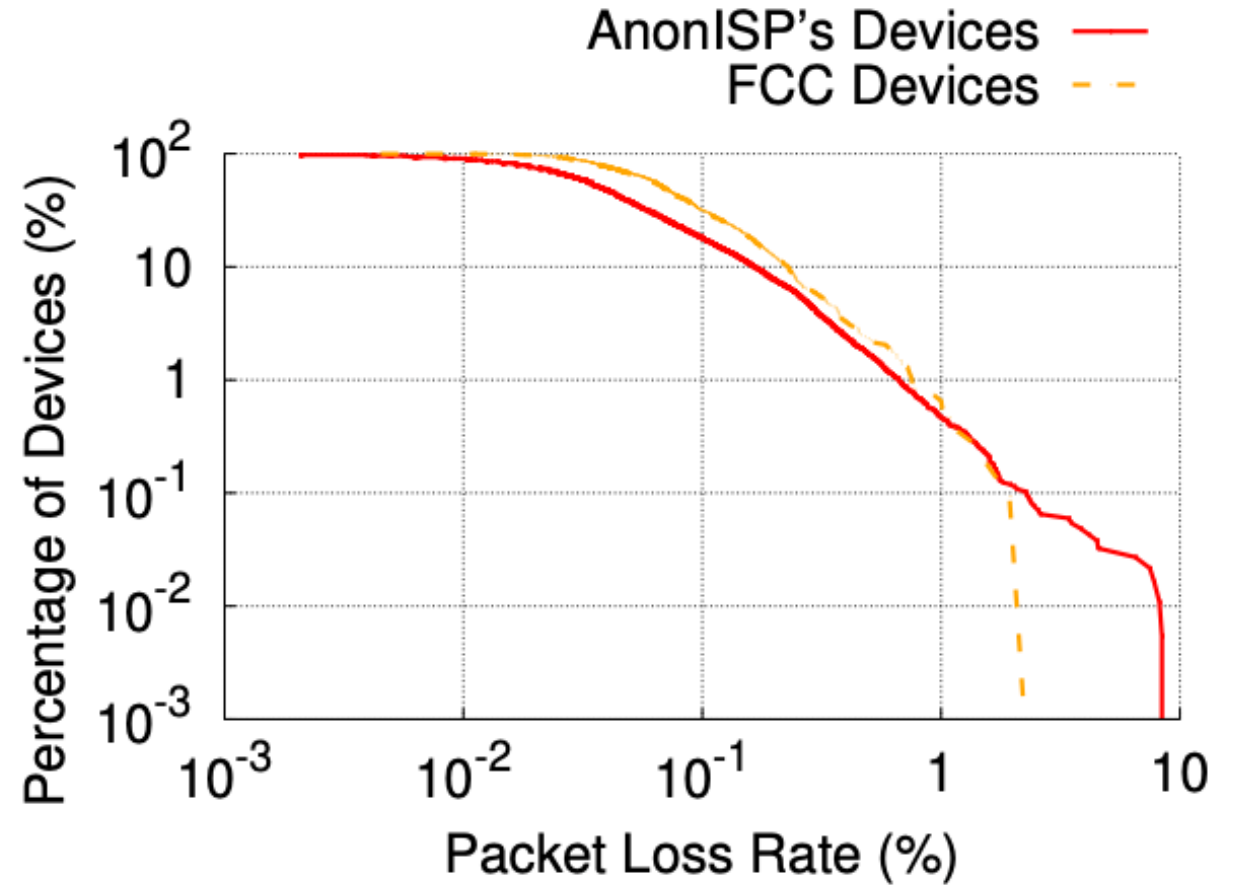
IP-layer Packet Loss Statistics
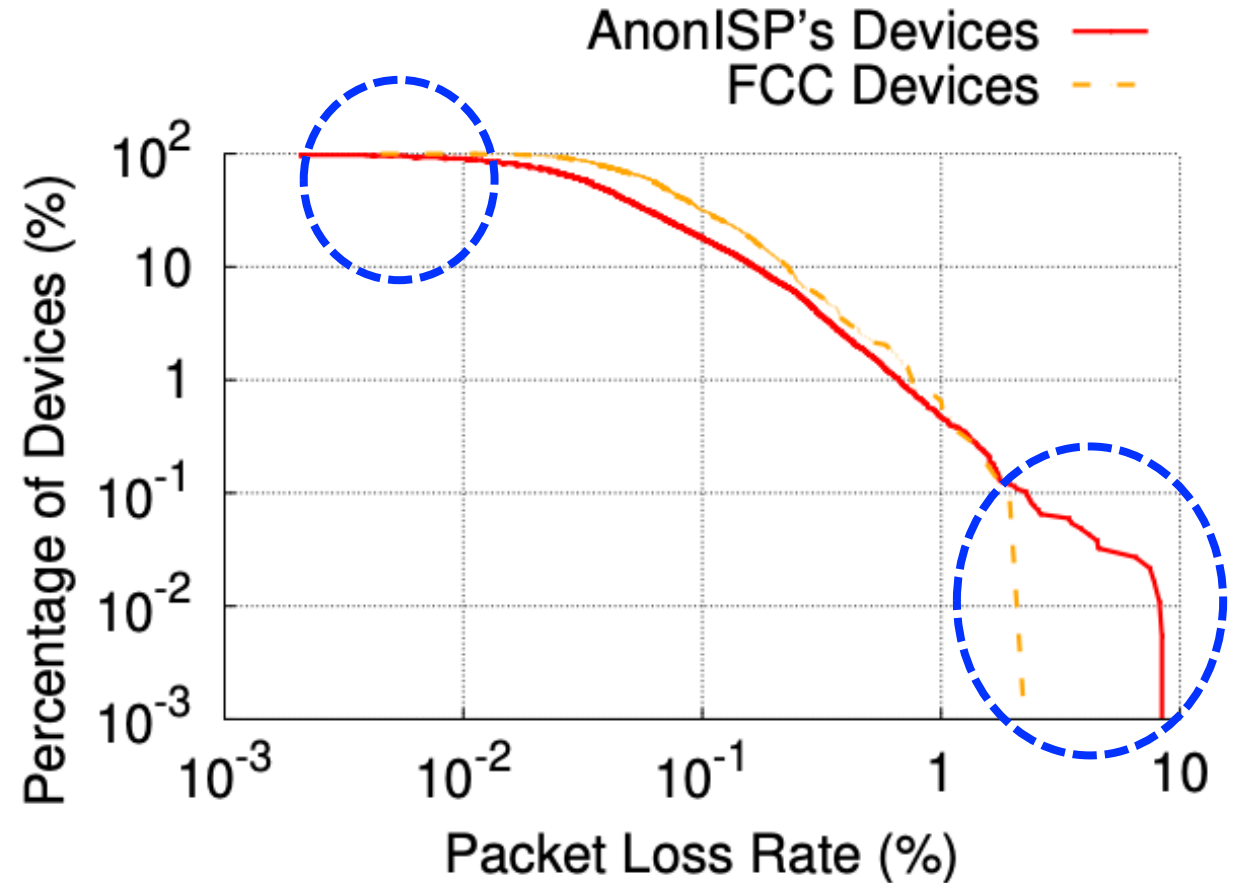
- Wider range

IP-layer Packet Loss Statistics

- Wider range

- AnonISP: 19k devices
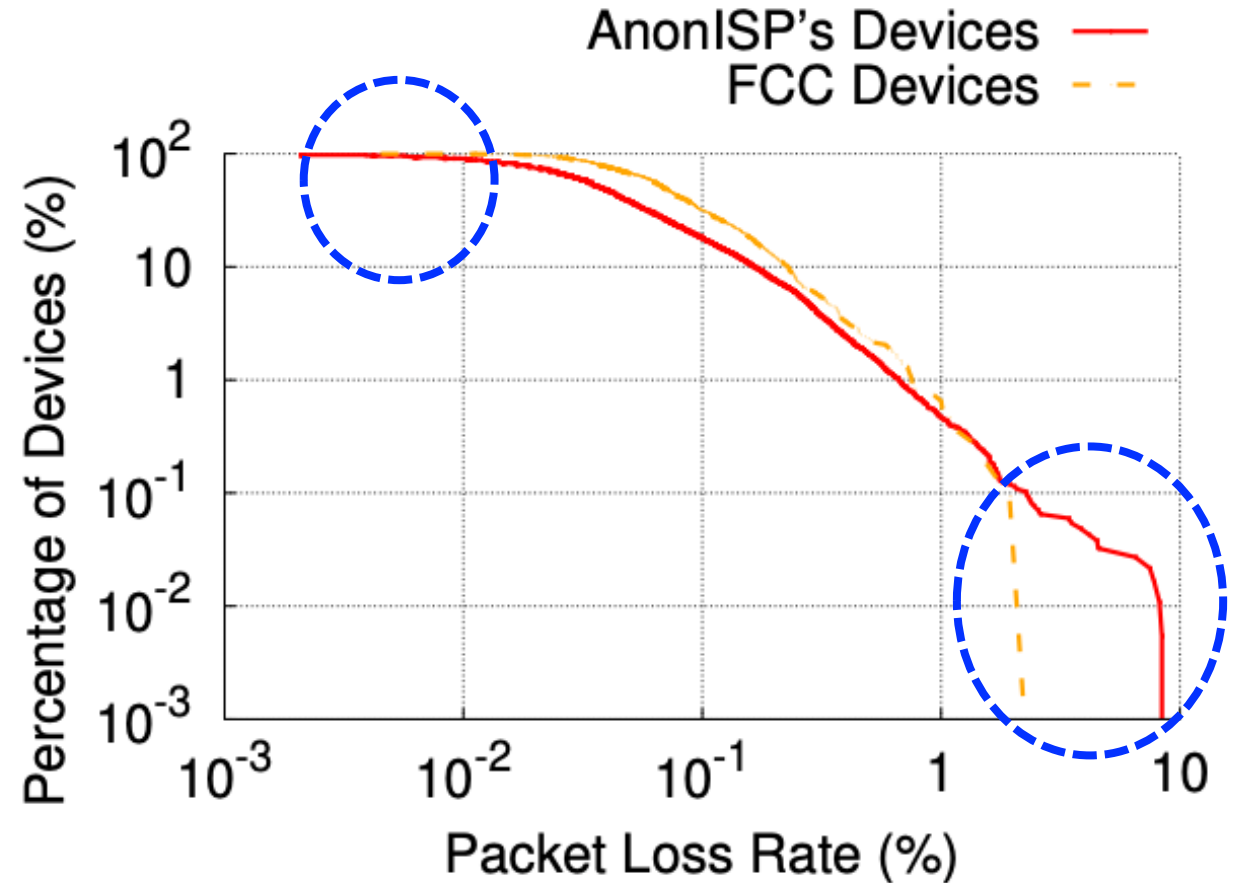
- FCC: 1k devices

IP-layer Packet Loss Statistics

- Wider range

- AnonISP: 19k devices

- FCC: 1k devices

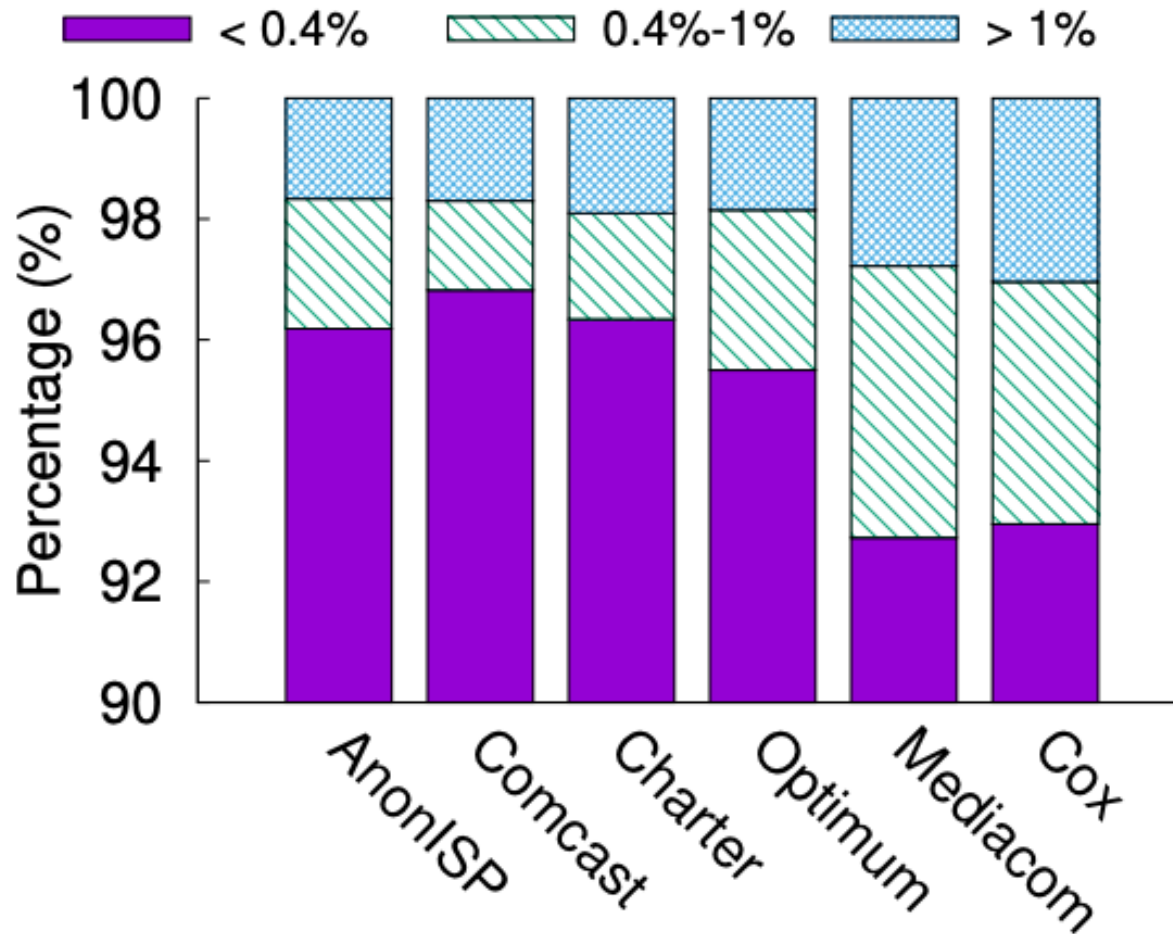- Similar distribution
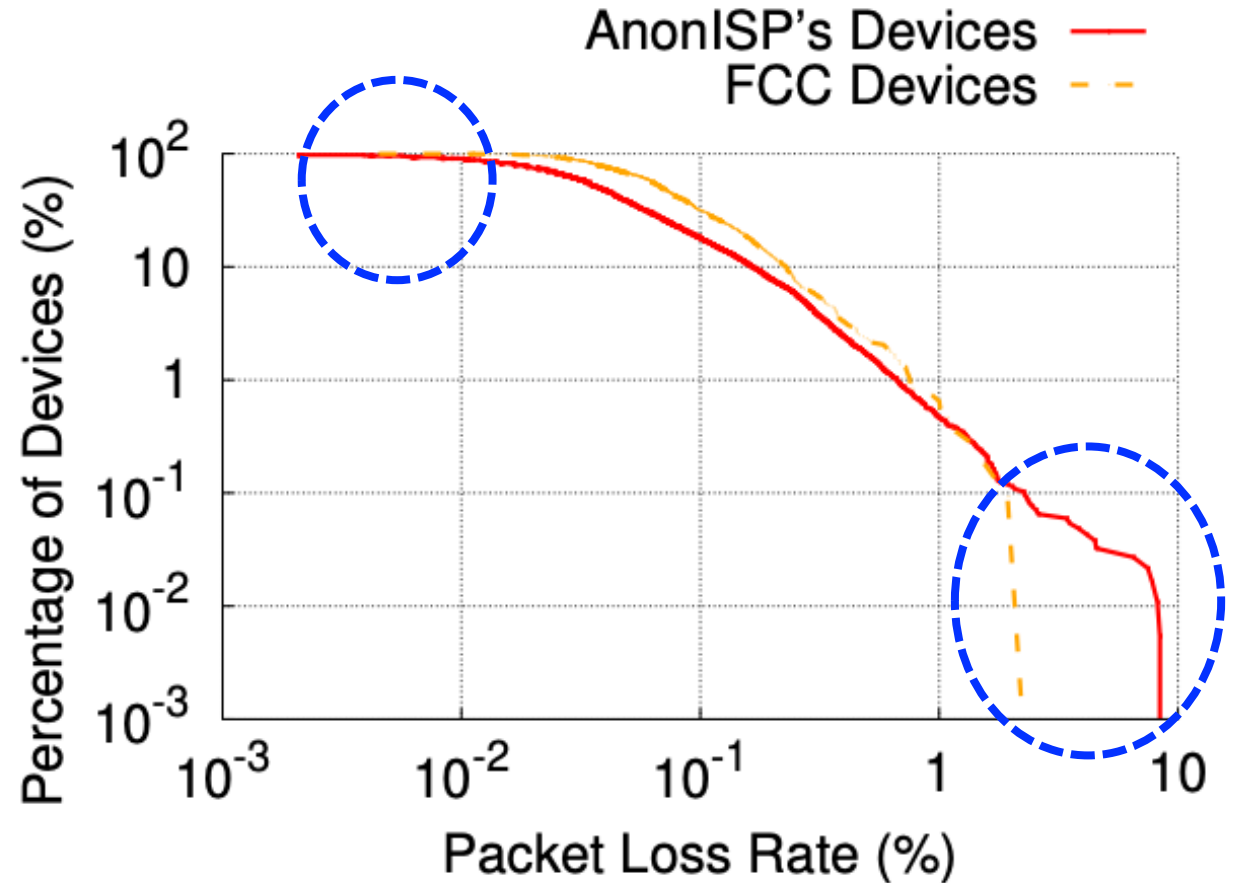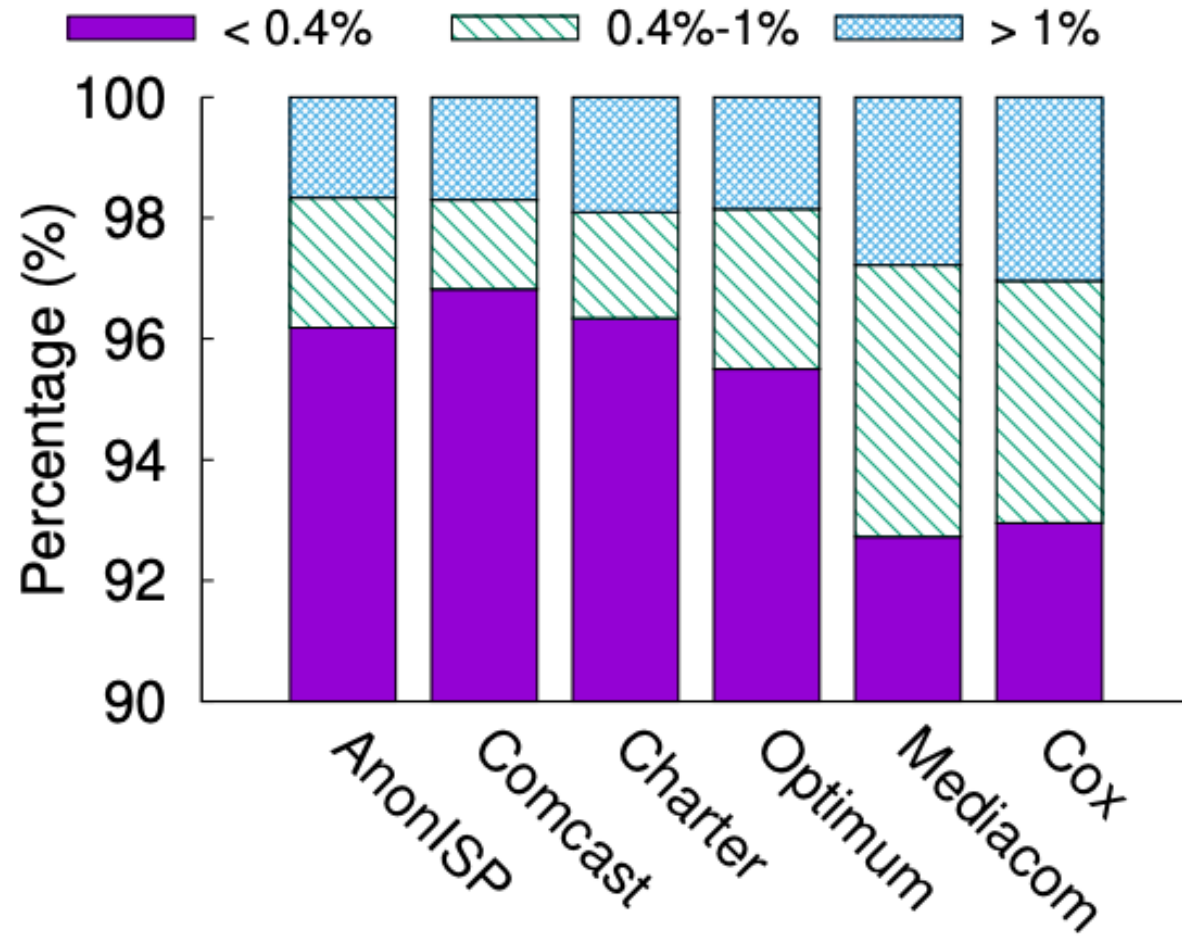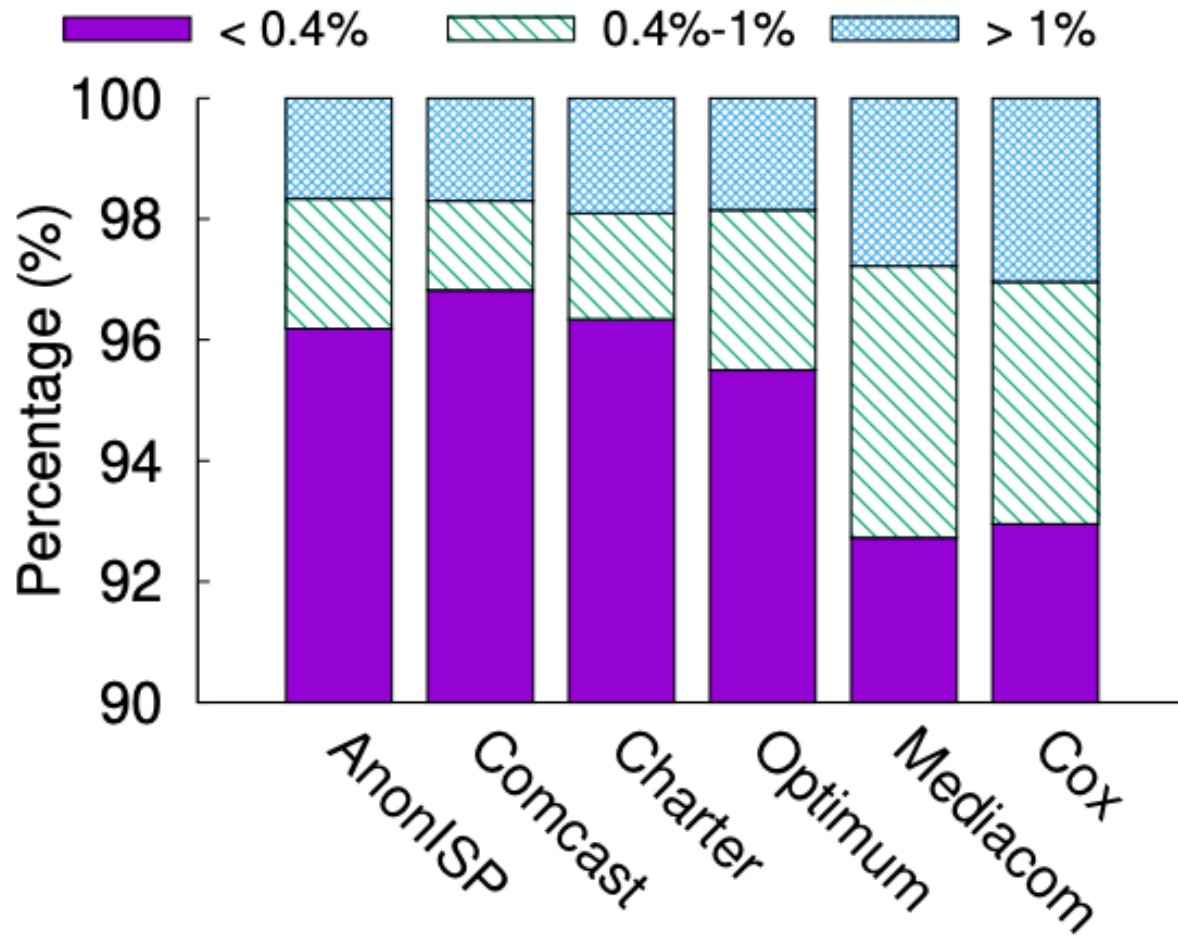
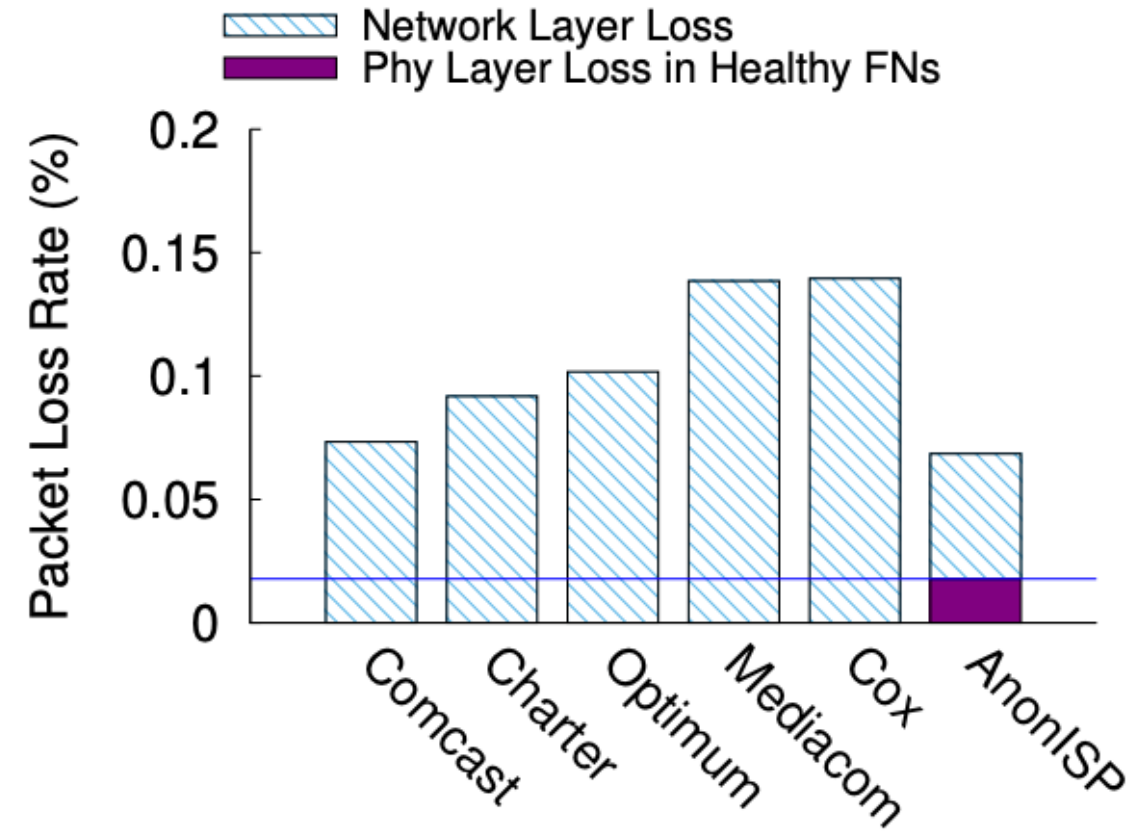# IP-layer Packet Loss Statistics

IP-layer Packet Loss Statistics

- AnonISP, Comcast, Charter and Optimum have similar distribution
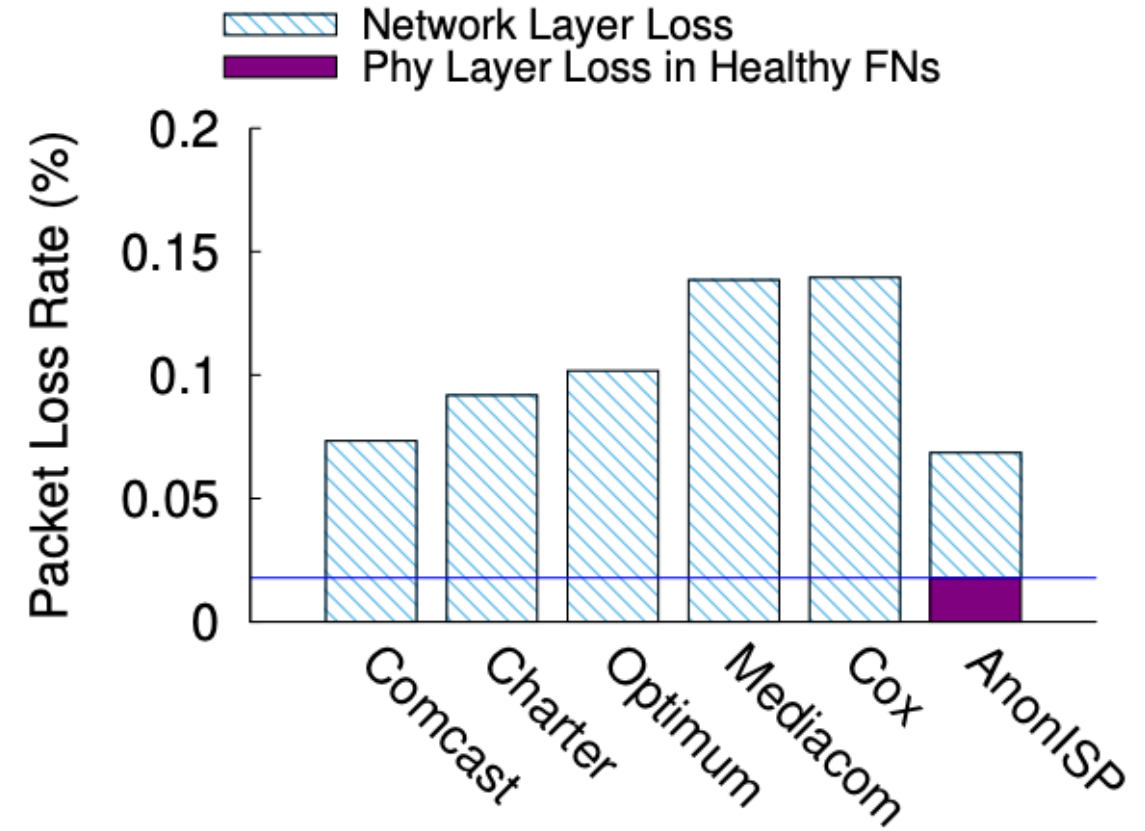
IP-layer Packet Loss Statistics

- AnonISP, Comcast, Charter and Optimum have similar distribution

- AnonISP's cable network is representative

How Many Packet Losses are from Physical-Layer?

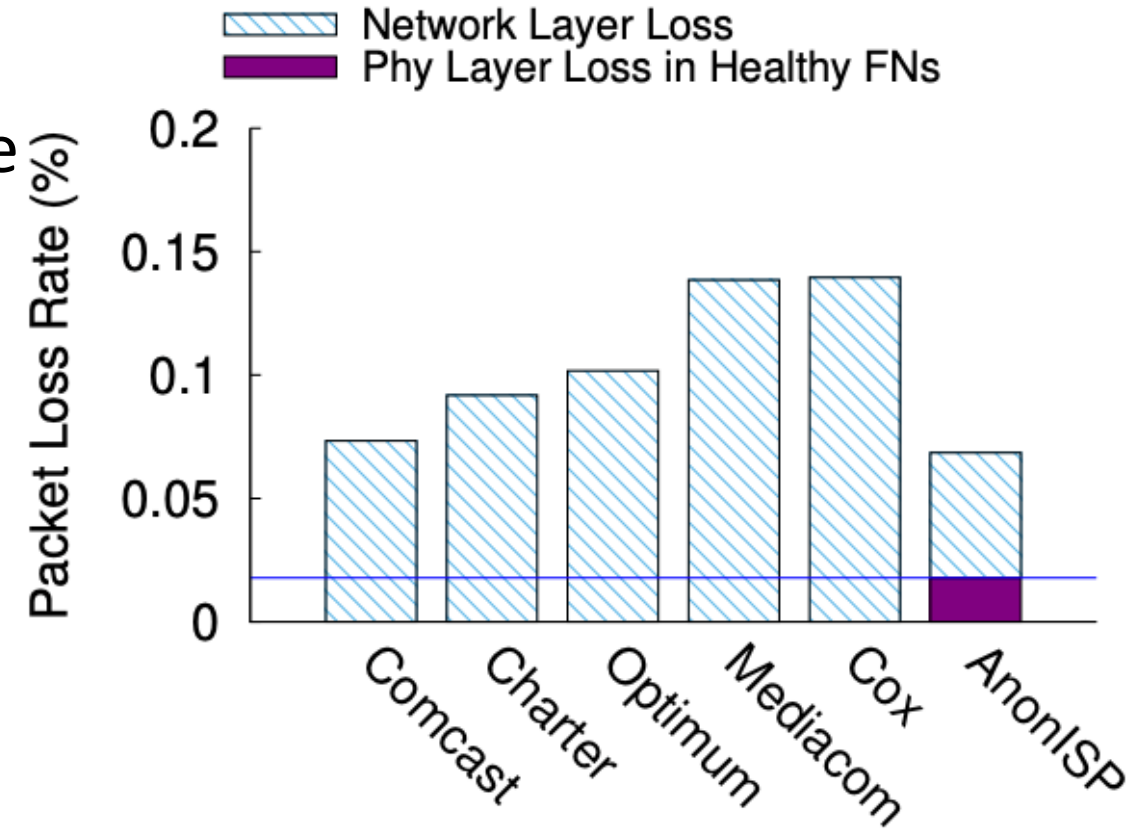# How Many Packet Losses are from Physical-Layer?

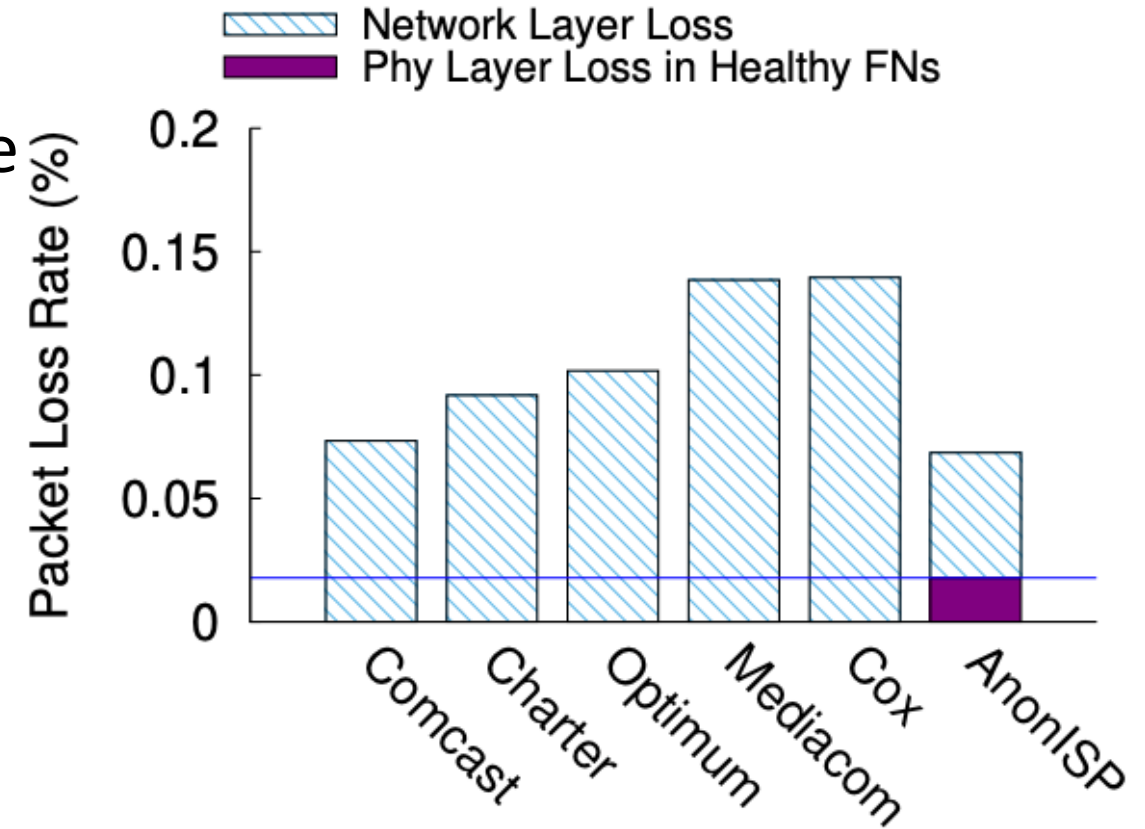- 1 measurement packet = One short codeword

How Many Packet Losses are from Physical-Layer?

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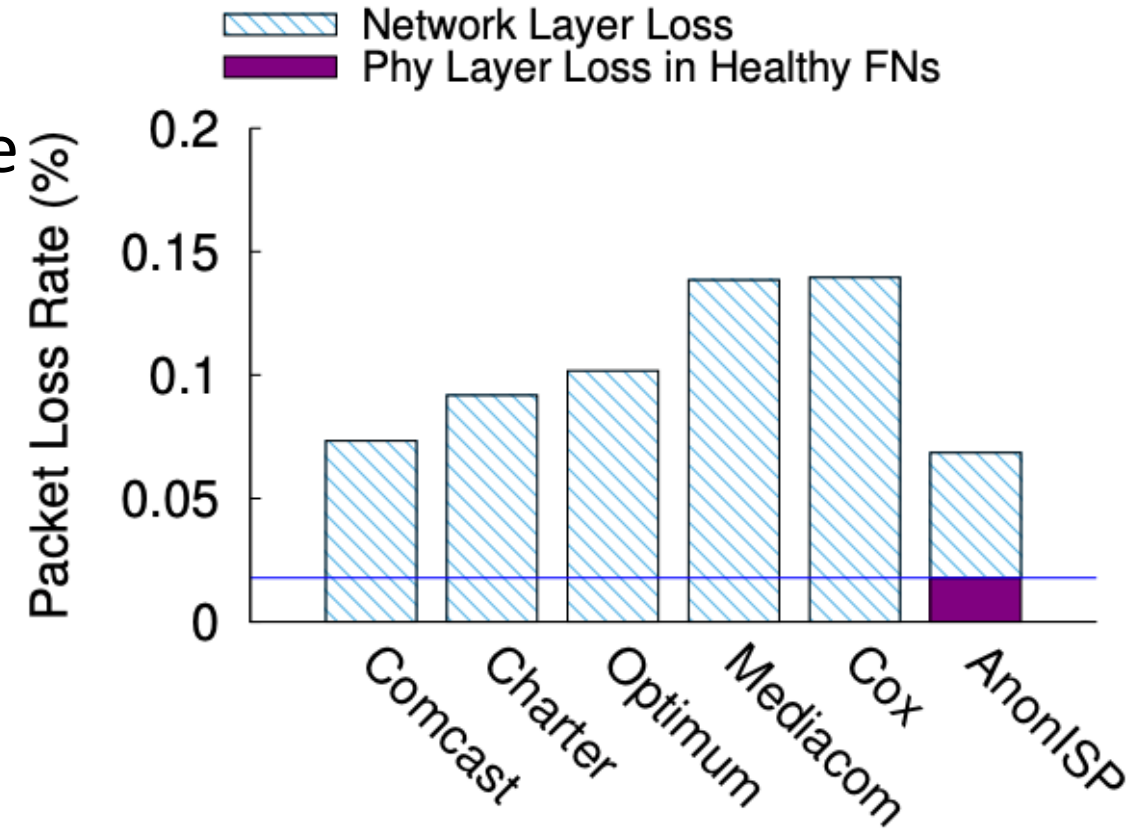 - Packet loss rate ≈ codeword error rate

How Many Packet Losses are from Physical-Layer?

- 1 measurement packet = One short codeword
  - Packet loss rate ≈ codeword error rate

- Physical-layer –> 12% to 25%

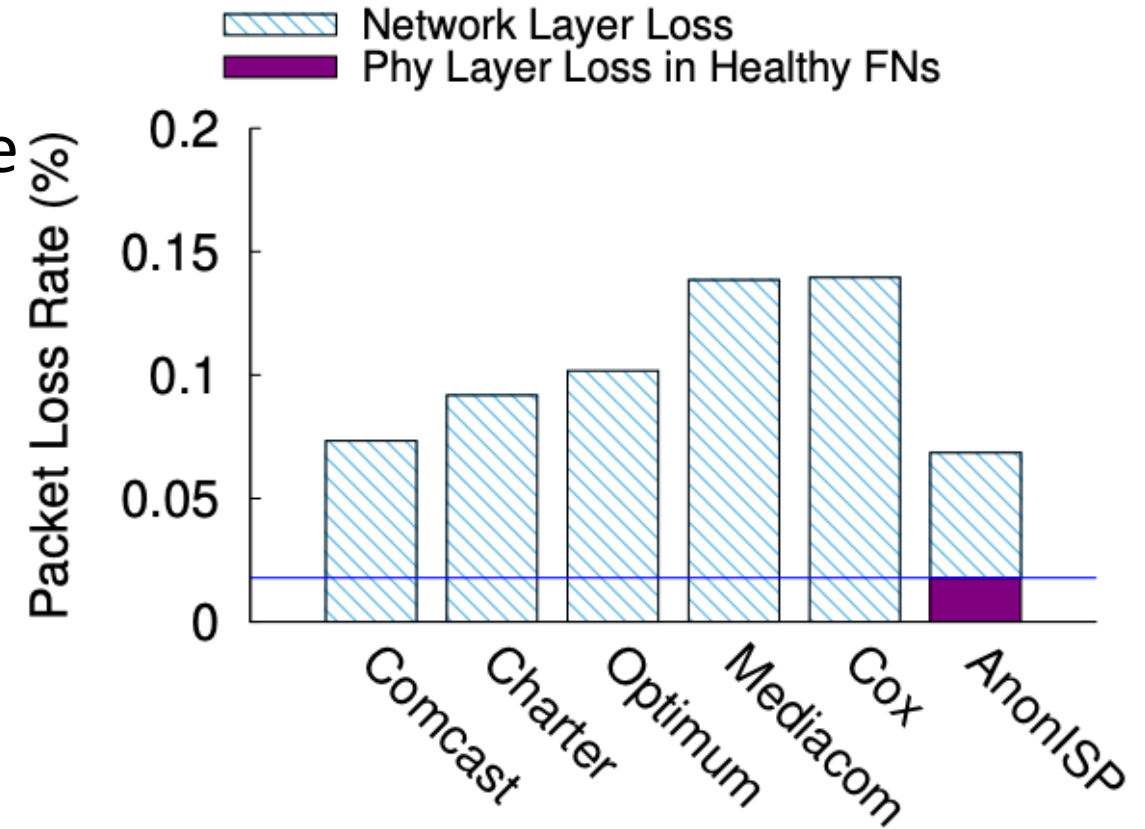# How Many Packet Losses are from Physical-Layer?

- 1 measurement packet = One short codeword
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- Physical-layer –> 12% to 25%
    - Lower bound estimate

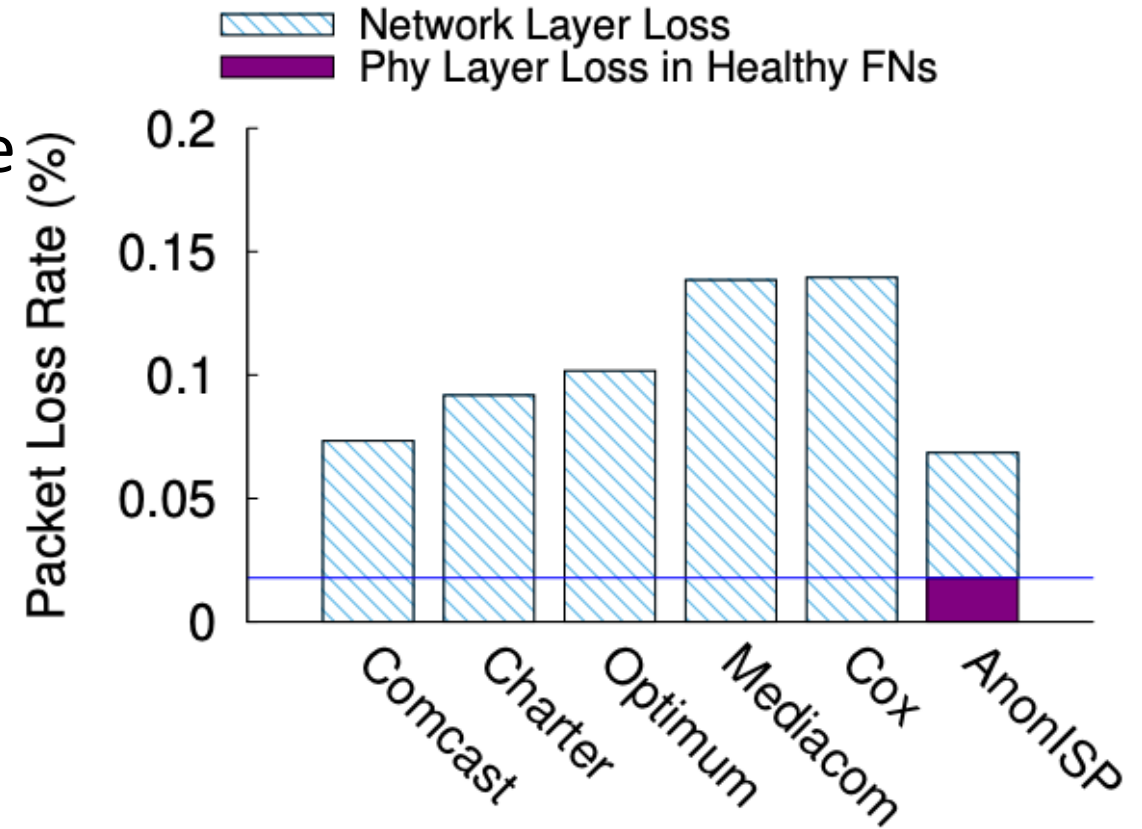# How Many Packet Losses are from Physical-Layer?

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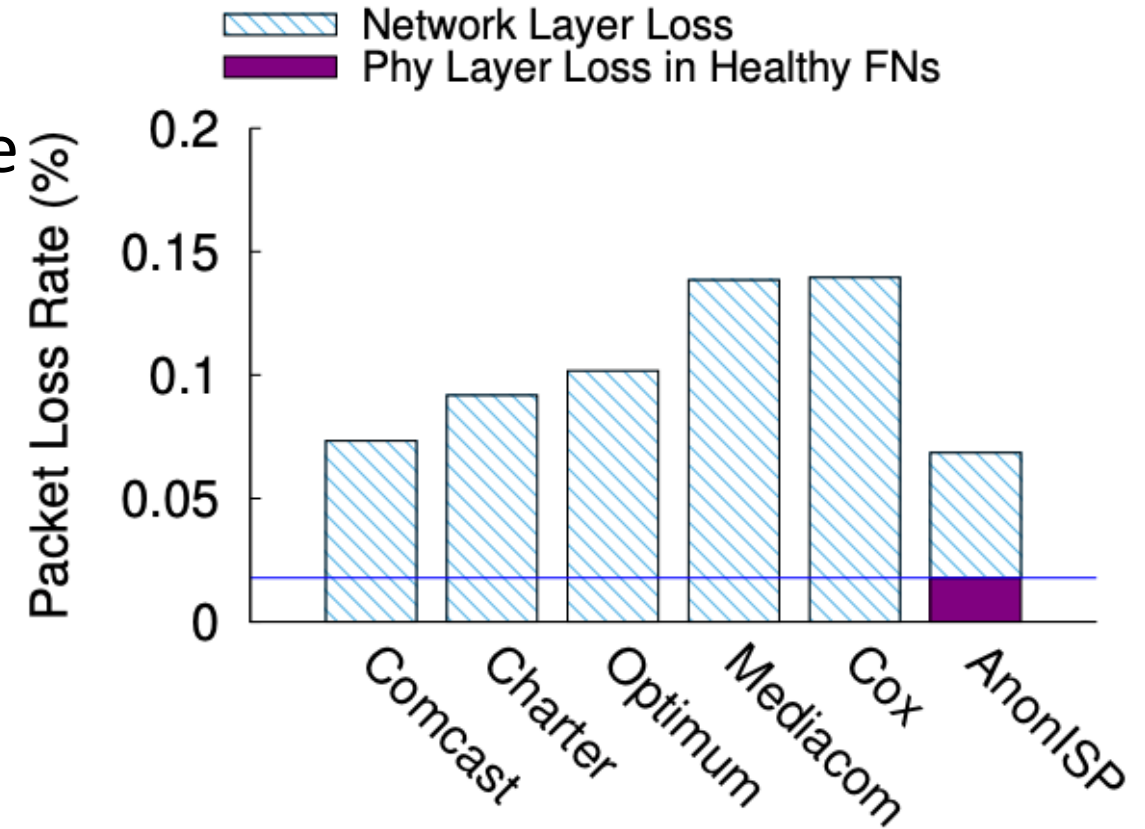- Physical-layer –> 12% to 25%
  - Lower bound estimate
    - PNM: Last-mile

How Many Packet Losses are from Physical-Layer?

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    - FCC: Last-mile + more hops

How Many Packet Losses are from Physical-Layer?

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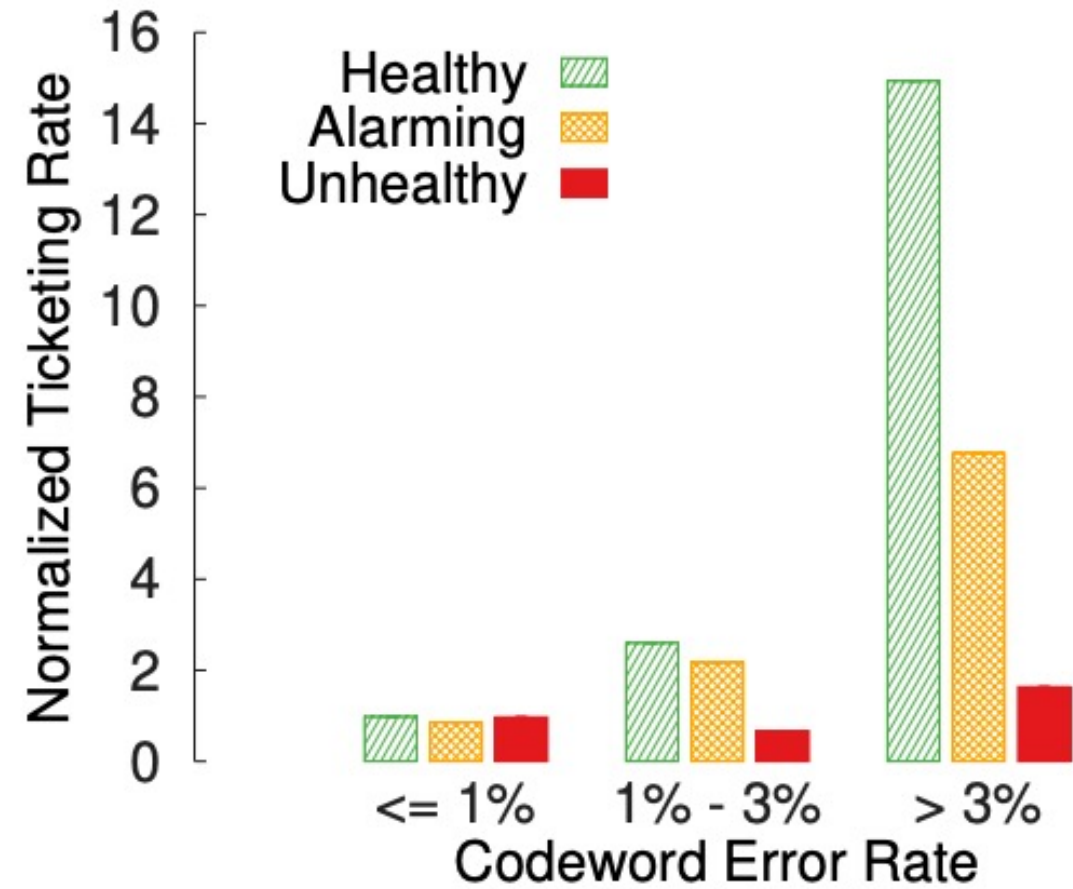   - FCC: Last-mile + more hops

Packet loss caused by physical layer is not negligible

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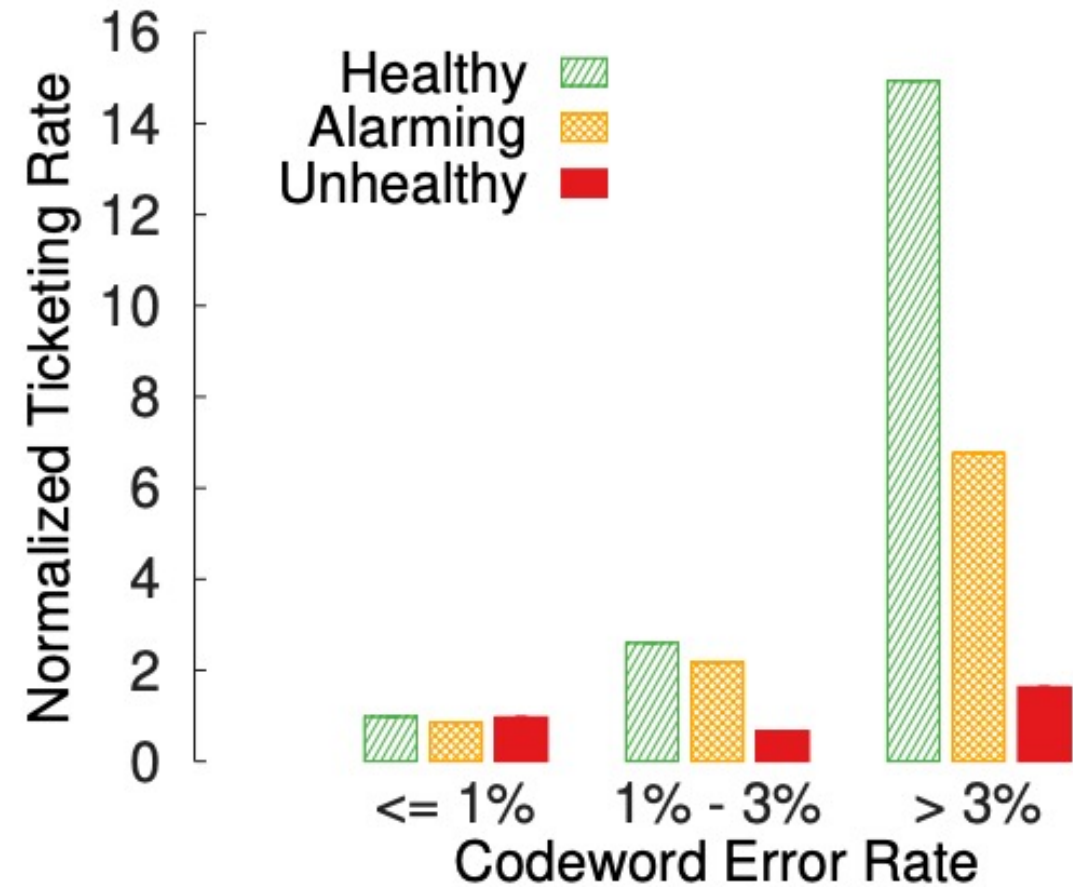
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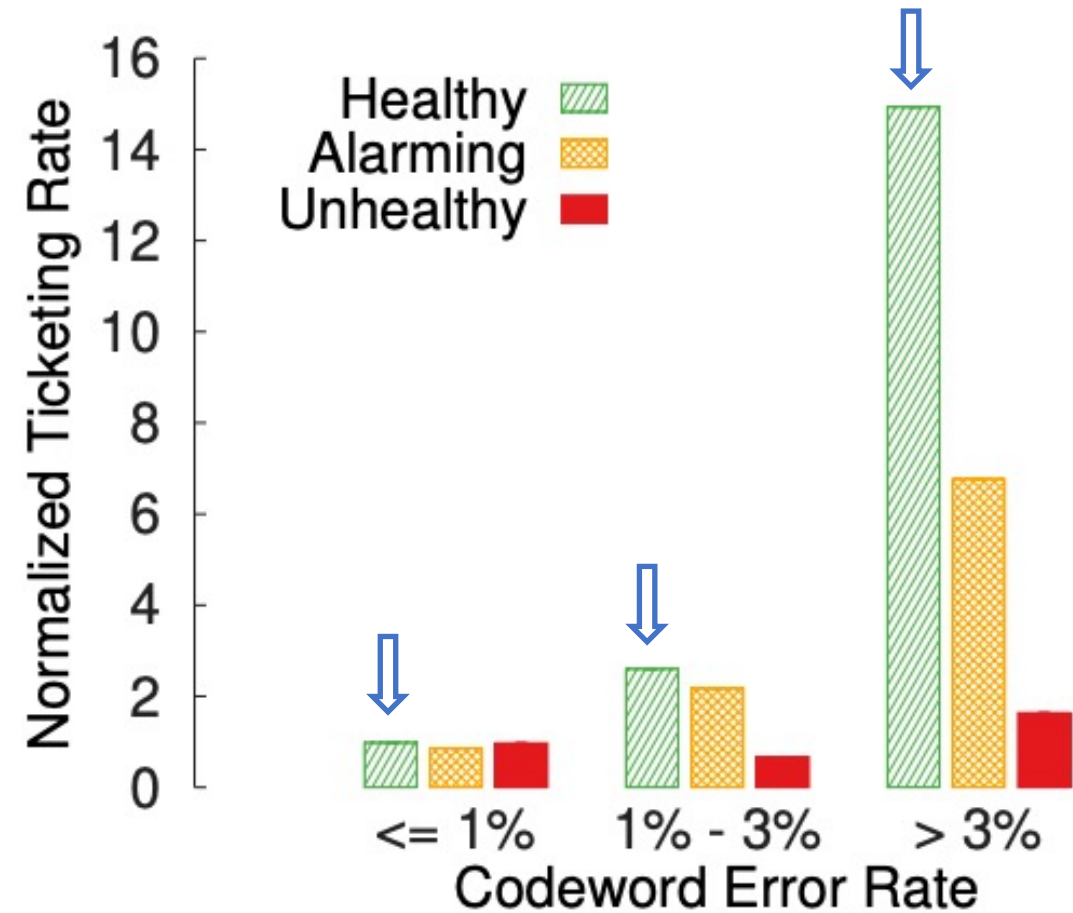
Customers Report More Tickets

Customers Report More Tickets

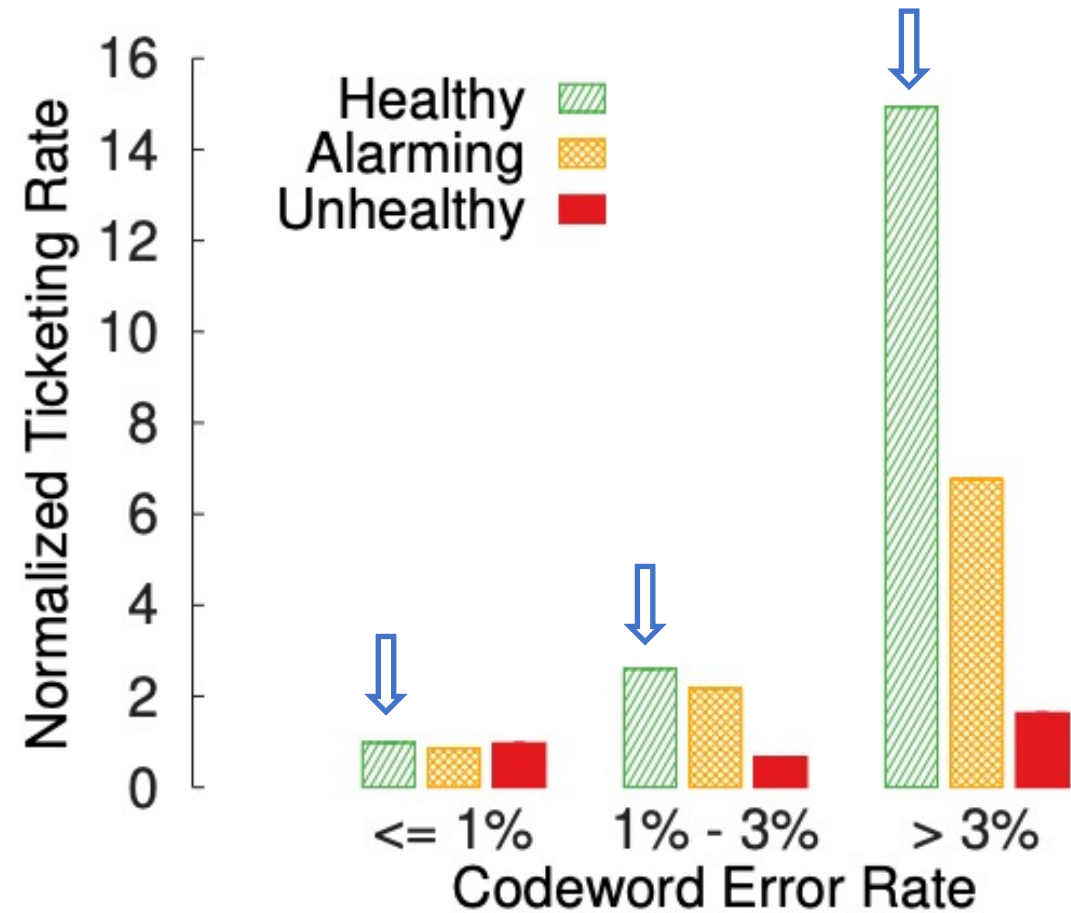- Ticketing rate = $\dfrac{\#\ of\ ticket}{Total\ time}$

Customers Report More Tickets

- Ticketing rate = $\dfrac{\text{\# of ticket}}{\text{Total time}}$

Customers Report More Tickets

- Ticketing rate = $\dfrac{\textit{\# of ticket}}{\textit{Total time}}$
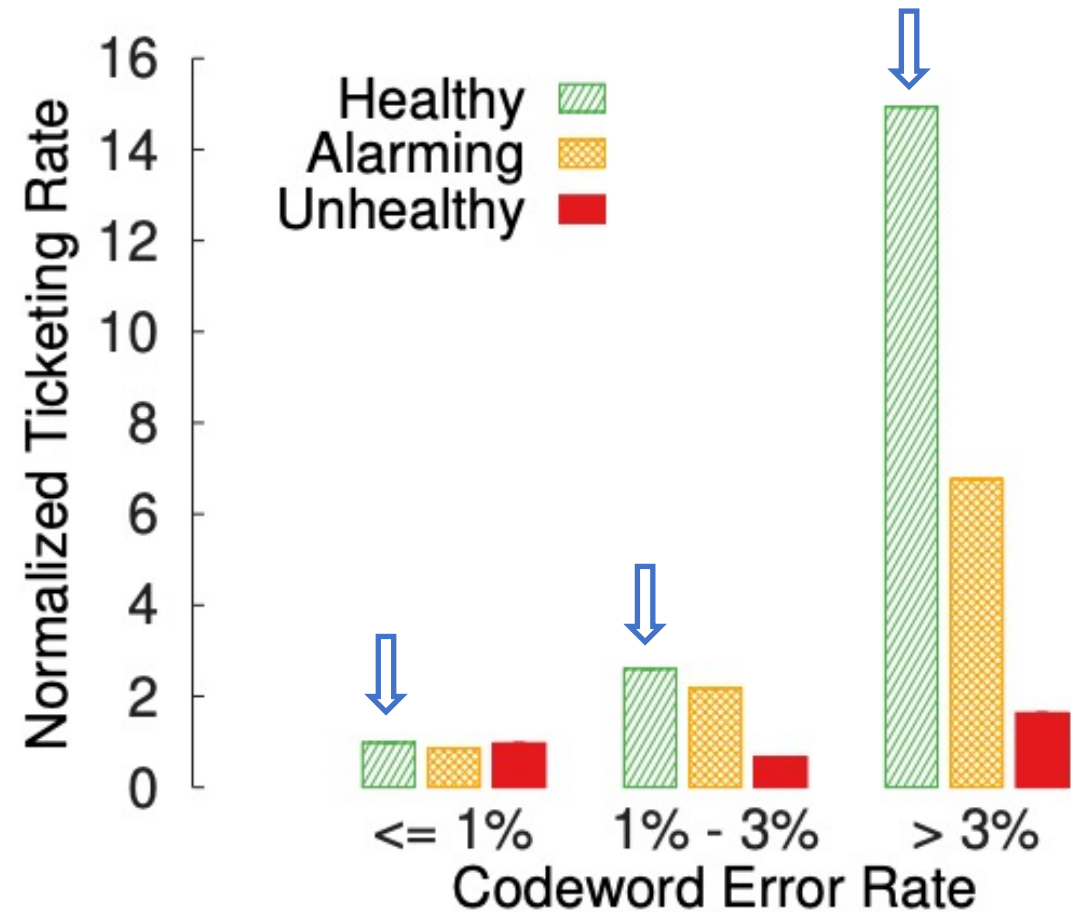
- High codeword error rate -> more tickets

Customers Report More Tickets

- Ticketing rate = $\dfrac{\text{# of ticket}}{\text{Total time}}$

- High codeword error rate -> more tickets

- Customers in alarming and unhealthy FNs -> higher tolerance for packet loss

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- Results
  - Overview of physical-layer transmission errors
  - Physical-layer transmission errors vs. Overall packet losses
  - Effects on customer behaviors
  - What factors affect physical-layer transmission errors
- Implications & Conclusion

Implications and Conclusions

- Wired networks can have high physical-layer packet loss rates

- Physical-layer error loss contributes to 12% to 25% packet loss

- Absence of trouble tickets ≠ absence of network issues

- Packet loss measurements should use variable packet lengths

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Thanks! Q & A

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