End-to-End Detection of Middlebox Interference

Vahab Pournaghshband
Network and Security Laboratory (Nets Lab)
Computer Science Department
University of San Francisco
vahab.p@usfca.edu

Peter Reiher
Laboratory of Advanced System Research
Computer Science Department
UCLA
reiher@cs.ucla.edu
Motivation

• Middleboxes
  • RFC 3234: “any intermediary device performing functions other than the normal, standard functions of an IP router on the datagram”
• Middleboxes are prevalent
• They can interfere with traffic
• Detecting middleboxes is important
  • Performance, security, debugging network issues
Motivation

• **Transparent middleboxes**
  • A class of middleboxes that make no changes to the content of traffic, giving the appearance that nothing has been done to the traffic stream
  • Examples: eavesdropping, compressing/decompressing, dropping or delaying packets, encrypting/decrypting, etc.

• Detecting transparent middleboxes is challenging

• **Current practice**: if I want to show a middlebox is detectable, I develop a tool to detect the middlebox
  • We have many point solutions
Our Contribution

• Detecting a broader class of middleboxes
• Introducing a reduction framework to determine if a middlebox is detectable via only analytical means
Detectable Abstract Middlebox

MB1

MB2
Detectable Abstract Middlebox

MB1

MB2

MB3
Network Flow Discriminator
Network Compression

Traffic Shaping/Policing

Traffic Prioritization

Network Flow Discriminator
We reduce the problem of “is MB detectable” to the problem of “is discriminator detectable” by showing that MB is a discriminator.
Roadmap

• Network Discriminators
• Detecting Network Discriminators
• Detection Framework
• Detecting Traffic Prioritization
• Results
• Future Work
• Summary
Notations

- $P_A$: A packet with predefined property $A$
- $P_B$: A packet with predefined property $B$
- $MB$: The middlebox in question
- $t_a(P)$: Arrival time of the last bit of packet $P$ to the middlebox
- $t_d(P)$: Departure time (time to transmit the first bit of packet $P$ into the middlebox)
- $d_{MB}(P): = t_d(P) − t_a(P)$
Notations

- $t_T$: Transmission time
- $c_p$: The path capacity
- $Z$: The link capacity of the outgoing link from $MB$
- $r$: sender’s sending rate of the probe packets as perceived by $MB$
Definition: Delay-Discriminatory Sets

An ordered pair of sets of packets \((P_A, P_B)\) are said to be delay-discriminatory if:

1. \(|P_A| = |P_B| \neq 0\)
2. \(\exists P_{A_i} \in P_A, \exists P_{B_j} \in P_B:\)
3. \(\delta_i = d_{MB}(P_{A_i}) - d_{MB}(P_{B_j}) \geq \delta_{min} > 0\)
   
   and
4. \(t_T(P_{A_i}) \geq t_T(P_{B_j})\)
   
   and
5. \((P_A - \{P_{A_i}\}, P_B - \{P_{B_j}\})\) is also delay-discriminatory or is \((\emptyset, \emptyset)\)
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and

\[
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and

\[ t_T(P_{A_i}) \geq t_T(P_{B_j}) \]

and

\((P_A - \{P_{A_i}\}, P_B - \{P_{B_j}\})\) is also delay-discriminatory or is \((\emptyset, \emptyset)\)
Definition: Network Flow Discriminator

A middlebox $MB$ is a network flow discriminator if, given $d_{MB}()$, there exists a pair of non-empty sets of packets $(P_A, P_B)$ that is delay-discriminatory.

i.e., $\delta_{min} = \min_{\forall i} \delta_i > 0$
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Packet drops: $\delta_i = +\infty$
Discriminator is Detectable

• We show that there exists a solution to detect discriminators
• Send packet trains of $P_A$ and $P_B$

$$(P_{A_j})_{j=1}^\rho := (P_{A_1}, P_{A_2}, \ldots, P_{A_\rho}), (P_{B_j})_{j=1}^\rho$$
The relationship between $d_{MB}$ and $c_p$ in detecting a discriminator ($\Delta l > \tau$), where $\rho=1000$, $c_p=r$
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Discriminator is Detectable

\[ \delta_{\text{min}} = \Theta \geq 1\text{ms} \]

\[ d_{MB}(P_{Bi}) < \theta = 10\mu s \forall i \]

The relationship between \( d_{MB} \) and \( c_p \) in detecting a discriminator (\( \Delta l > \tau \)), where \( \rho = 1000 \), \( c_p = r \)
Detection Framework

To show that a particular middlebox $MB$ is detectable, it is sufficient to show:

1. $MB$ is a discriminator. I.e., there exists a pair of non-empty sets $(P_A, P_B)$ that is delay-discriminatory.
2. $\delta_{\text{min}} \geq \Theta = 1ms$, where $\delta_{\text{min}} := \min\{\delta_i : 1 \leq i \leq \rho\}$.
3. $\forall i, d_{MB}(P_{B_i}) \leq \theta = 10\mu s$
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Detecting Traffic Prioritization

- Strict Priority Queueing (SPQ)
Detecting Traffic Prioritization

To show that SPQ is detectable, it is sufficient to show:

1. *SPQ* is a discriminator. I.e., there exists a pair of non-empty sets \((P_A, P_B)\) that is delay-discriminatory.

2. \(\delta_{min} \geq \Theta = 1ms\), where \(\delta_{min} := \min\{\delta_i: 1 \leq i \leq \rho\}\).

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Detecting Traffic Prioritization

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2. \( \delta_{\text{min}} \geq \Theta = 1\text{ms} \), where \( \delta_{\text{min}} := \min\{\delta_i : 1 \leq i \leq \rho\} \).

3. \( \forall i, d_{MB}(P_{B_i}) \leq \theta = 10\mu s \)
Detecting Traffic Prioritization

- $P_H$: The packet that is prioritized.
- $P_L$: The packet that is not prioritized.
Assuming \( r > Z \), to accomplish these objectives, the following conditions must hold:

(i) High priority packets in \( HP \) are sent at the rate of \( \frac{r}{N'+1} \). Hence, for \( Q_H \) to never build up, \( \frac{r}{N'+1} \leq Z \) must hold.

(ii) High priority packets in \( LP \) are sent at the rate of \( \frac{N'}{N'+1} r \). Therefore, for \( Q_H \) to never be empty, the condition \( \frac{N'}{N'+1} r \geq Z \) must be satisfied.

Combining conditions (i) and (ii), we have \( \frac{r}{N'+1} \leq Z \leq \frac{N'}{N'+1} r \). We can now solve for \( N' \):

\[
N' \geq \lceil \max \left\{ \frac{r - Z}{Z}, \frac{Z}{r - Z} \right\} \rceil
\]
Detecting Traffic Prioritization

To show that SPQ is detectable, it is sufficient to show:

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2. \(\delta_{min} \geq \Theta = 1ms\), where \(\delta_{min} := \min\{\delta_i : 1 \leq i \leq \rho\}\).

3. \(\forall i, d_{MB}(P_{Bi}) \leq \theta = 10\mu s\)
Detecting Traffic Prioritization

\[ d_{MB}(P_H) = 0 \]
Detecting Traffic Prioritization

\[ d_{MB}(P_H) = 0 \]

\[ \delta_i = d_{MB}(P_{Li}) \]
Detecting Traffic Prioritization

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Detecting Traffic Prioritization

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\[ \delta_i = +\infty \]

\[ \delta_i \geq N' \cdot \rho \cdot t_T(P_H) \]
Detection Tool Development

• The analytical reduction inspired us to develop a tool to detect the middleboxes
• Traffic prioritization:
Results: Environment Setup
Results

![Graph showing data points for PL1, PL2, PL3, and PL4 with error bars for Compression, Shaping, and SPQ categories.](image-url)
Ongoing and Future Work

• We are/will
  • Formulate additional abstract classes
  • Explore alternative solutions to detect discriminators
  • Identify more middleboxes whose interference can be described as discriminators

• We are investigating detecting middleboxes in dynamic environment
Summary

• We showed
  • An example of an abstract class: discriminators
  • A loss-based solution to detect discriminators
  • Three middleboxes---network compression, traffic shaping and prioritization---whose interference are described as discriminators