Tools for Active and Passive Network Side-Channel Detection for Web Applications

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Agenda

Introduction

- Cryptography as go-to solution for communication security in insecure environments.
- Even under properly implemented cryptosystems, information such as packet timings and session lengths still remains intact.
- Related research has shown that it is possible to learn *sensitive* information from observing these information features.
- Unlike more direct information leaks such as *SQL Injections*, the current state of research for detection tools based on known-to-be-vulnerable design patterns still lags behind.

SSL/TLS

- Secure Sockets Layer (SSL) and its successor, Transport Layer Security (TLS) are popular cryptographic protocols for maintaining the *confidentiality*, *authenticity* and *integrity* of a web session.
  - Works by using public key cryptography to exchange a *symmetric* encryption and authentication key.
  - A list of certificate authorities is trusted to endorse, by public key signature, the public key certificate for an SSL/TLS using website.
  - The protocol is used on every *HTTPS* URL.

Threat Model

- The protocol is designed to maintain *confidentiality*, *authenticity*, and *integrity* even if **network traffic can be intercepted or manipulated**.
- The protocol *should* allow a developer to wrap their plaintext TCP connections with SSL/TLS and the above three information security properties should be upheld.
- Any violation of these properties would be a case where SSL/TLS does not perform sufficiently to satisfy its threat model.

Practically Speaking

- Wi-Fi snooping
- Compromising internal network equipment for ARP/IP/DNS spoofing
- Malicious VPNs or proxies
- Malicious ISPs
- Illegal wiretapping
- Etc...

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Underlying Concepts

- A fundamental understanding of the interaction between computer networks and modern web development is necessary for understanding the side-channel vulnerabilities in SSL/TLS.
- One must be aware that SSL/TLS does not hide the following information:
  - Approximate size of data transferred in a session
  - Start and end times of each session
  - IP addresses and domain names of clients and servers
  - Order of sessions

Network Traffic Features

- Let us consider measuring the approximate size of a session:
  - Maximum payload size of Ethernet frame is **1500 bytes**.
  - Minimal size of IP header is **20 bytes**.
  - Minimal size of TCP header is **20 bytes**.
  - Therefore maximum HTTP payload carried in one Ethernet frame is **1460 bytes**.
  - Our empirical observations have shown the maximum HTTP payload size to be **1370 bytes**.
- Therefore session size can be estimated by finding the sum of continuous sequences of **1370 bytes**, plus the size immediately before, plus the size immediately after.

Network Traffic Features

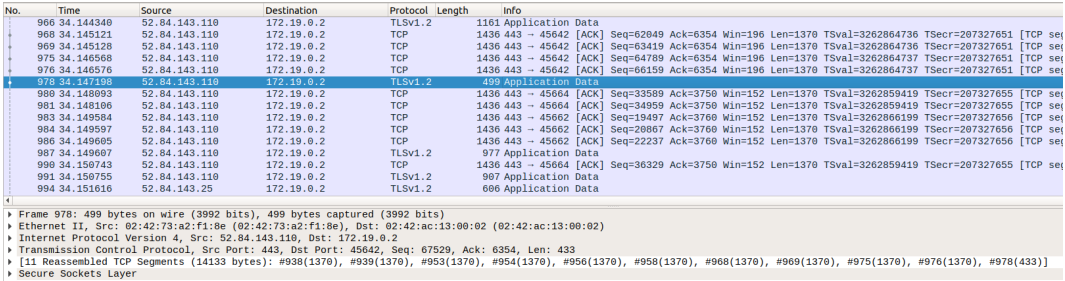


Figure: An approximation of session length can be recovered by summing continuous sequences of 1370 bytes.

Network Traffic Features

- Other useful features within a network traffic sample include:
  - Bursts of network activity
  - Timing between activity bursts
  - DNS information
  - Packet counting

Modern Web Development

- Web *applications*, not just web *pages*.
  - Real-time client-server communication (AJAX).
  - Responsivity
    - Lazy-loading of resources
    - Scalable protocols (ie. DASH)

Design

- Be able to exploit the following three *modern* web designs:
  - Response Dependant Page Loads
  - Real-time Feedback Systems
  - Lazy Loading

Exploiting Response Dependant Page Loads

- Remember, SSL/TLS is supposed to protect the *confidentiality* of a web application.
- Therefore, an adversary observing the encrypted communications of a web browser *should* be able to learn *nothing* on what the user has entered into an HTTPS submitted form.
- But what if the next page to be loaded depends on the responses submitted through this form?

Exploiting Real-time Feedback Systems

- Remember, using SSL/TLS does not hide the sizes of sessions nor the times at which they begin and end.
- Therefore, an adversary can learn:
  - When the real-time event occurred
  - The possible type(s) of the real-time event based on its size

Exploiting Lazy Loading

- A webpage with lazy loaded images will make different network requests dependant upon the geometry of the viewport.
- Remember that an adversary can *open and close* popup windows *in arbitrary sizes* to *cross-domain* webpages!

Exploiting Lazy Loading

- Therefore an adversary can learn about the page layout by observing the network traffic generated when loaded in different sizes.

exploit.js

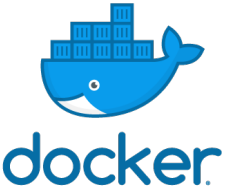
```
function do_popup(){
        var TARGET_URL = "https://targeturl.com/targetpage";
        popup_window = window.open(TARGET_URL,'targetWindow','toolbar=no,location=no,status=no,
                menubar=no, scrollbars=no, resizable=no, width=100, height=200');
        //Set a timer to close automatically close this window
        window.setTimeout(function(){
                popup_window.close();
        }, 10000);
}
```

Implementation

- Our tools were built with the help of several open-source software packages.
- This section discusses those packages which play primary roles in our tools.
- Understanding these packages is also necessary for future improvements to our tools.

Docker Container

- We would like to make our tests:
  - Isolated from normal computer use
  - Easily distributable and reproducible
- Docker is the perfect tool for this!



Dockerfile

```
FROM ubuntu:latest
RUN apt-get update
RUN apt-get install -y vnc4server jwm firefox
RUN apt-get install -y tcpdump
...
```

Linux Kernel Netfilter

- A subsystem of the Linux kernel allowing for network packet filtering and manipulation.
- Most commonly used through the *iptables* command.
  - *Netfilter Queue (NFQUEUE)* target of *iptables* allows for network traffic to be manipulated through user space programs!

nfqueue_example.py

```
def process(i, payload):
        payload.set_verdict(nfqueue.NF_DROP) #Drop all packets
q = nfqueue.queue()
q.open()
q.bind(socket.AF_INET)
q.set_callback(process)
q.create_queue(0)
```

Scapy

- A very robust Python library for packet creation, manipulation, and inspection.

scapy_example.py

```
from scapy.all import *
cap = rdpcap('captured_example.pcap')
len(cap)
>>> 1889
cap[281][IP].dst
>>> '172.19.0.2'
cap[281][IP].src
>>> '52.84.143.116'
cap[281][IP][TCP].sport
>>> 443
cap[281][IP][TCP].dport
>>> 44782
len(cap[281][IP][TCP].payload)
>>> 1370
```

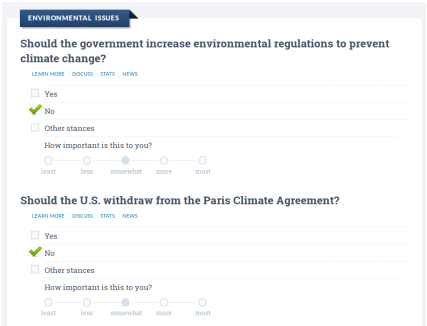
Evaluation

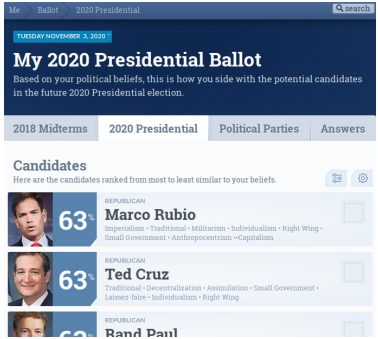
- We have discovered that through monitoring network traffic an adversary can:
  - Discover which political candidate is recommended for a user of *iSideWith.com*.
  - Determine which of the top ten Google searches of 2017 a user is likely searching for.
  - Estimate the number of items in a user's eBay shopping cart.
- These examples demonstrate the exploitation of the three vulnerable web designs discussed in this presentation; response dependant page loads, real-time feedback systems, and lazy-loading of web resources.

iSideWith.com

- iSideWith.com recommends a political candidate based on a user's responses to questions on divisive political issues.
- After submitting the questionnaire, a page displaying the recommended candidate is loaded.
- Therefore, the web design to be exploited in this example is *Response Dependant Page Loads*.

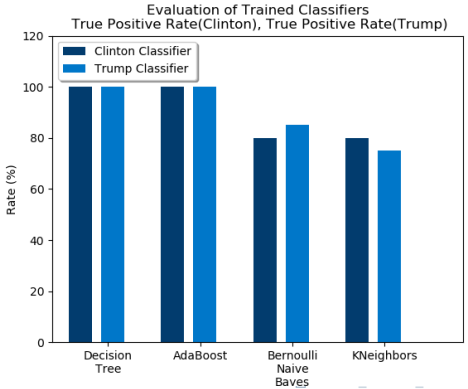
iSideWith.com





iSideWith.com

- Collected 80 *PCAP* network traffic capture files.
  - 40 corresponded to a recommendation of Donald Trump.
  - 40 corresponded to a recommendation of Hillary Clinton.
  - Captured data was split 50/50, training/testing.
- Evaluated various machine learning classifiers.



Analyzing Google Auto-Suggest

- Every keystroke entered into the *Google Search* bar results in a burst of network traffic sent to the server containing the search substring followed by a burst of network traffic sent from server to client containing the suggested search queries.
- By observing this encrypted network traffic, an adversary can learn:
  - The approximate number of keystrokes entered.
  - The sizes of the suggestion lists.

Analyzing Google Auto-Suggest

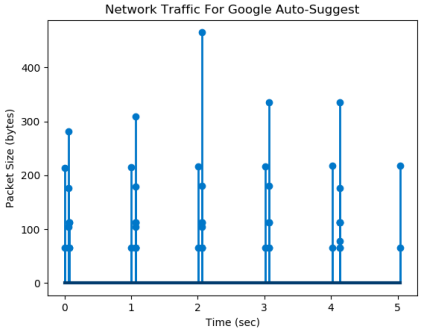
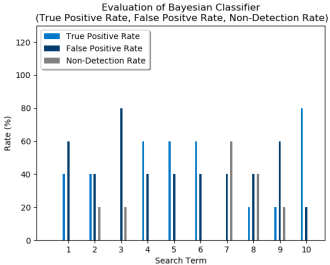


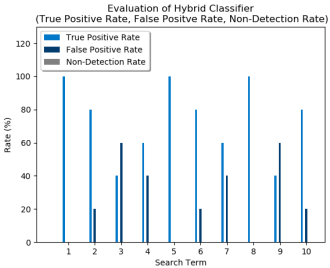
Figure: By observing the timing of network packets, counting the number of keystrokes entered becomes a trivial task.

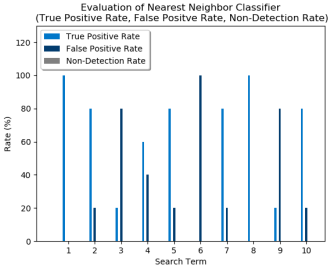
Analyzing Google Auto-Suggest

- For analyzing the Google Auto-Suggest traffic, the following machine learning approaches were taken:
  - Bayesian classification using number of bytes sent from server to client in each burst of network activity as well as the total number of bursts, as features.
  - Nearest neighbour classification using the total number of exchanged packets in a session.
  - A *hybrid* approach where the score is calculated as the Bayesian score divided by one plus the packet count distance.

Analyzing Google Auto-Suggest







Number	Search Term
1	Mayweather vs McGregor Fight
2	Las Vegas shooting
3	Hurricane Harvey
4	Solar Eclipse
5	Matt Lauer
6	Fidget spinner
7	Aaron Hernandez
8	Tom Petty
9	Hurricane Irma
10	Super Bowl

Censoring Google Auto-Suggest

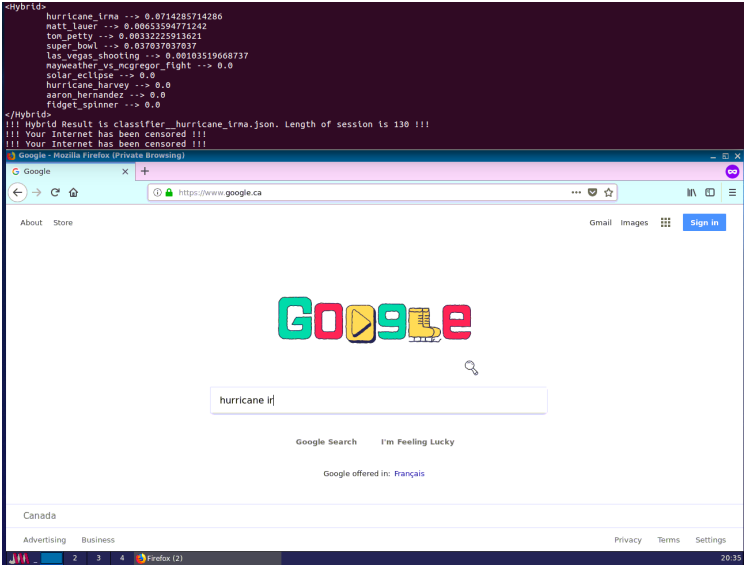
- Remember that SSL/TLS *should* protect the *integrity* of a web session.
- But if certain functionality can be detected and blocked then the *integrity* property is violated.
- What if we feed live network traffic to the Google Auto-Suggest classifier and use the output to control network traffic policy?

Censoring Google Auto-Suggest

realtime_google_filter.py

```
drop_traffic = False #Should traffic be dropped or not
captured_session = []
def process(i, payload):
        global drop_traffic
        data = payload.get_data()
        if drop_traffic:
                print "!!! Your Internet has been censored !!!"
                ...
                                payload.set_verdict(nfqueue.NF_DROP)
                return
                ...
                #Try to classify this session
                hybrid_result = getHybridClassifierType(captured_session,...)
                print "!!! Hybrid Result is {}. Length of session is {} !!!".format(...)
                for censor_item in CENSORSHIP:
                        ...
                        if hybrid_result == censor_label:
                                if len(captured_session) in range(size_min, size_max):
                                        drop_traffic = True #Flip the killswitch!
```

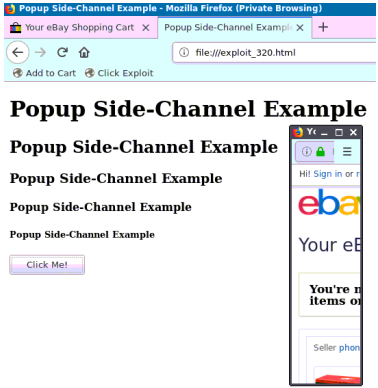
Censoring Google Auto-Suggest

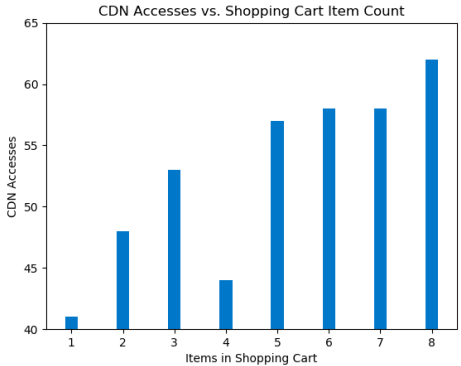


Counting eBay Cart Items

- Remember how on a page with *lazy-loaded* elements only the elements which are within the viewport are downloaded over the network.
- Therefore, if expanding the geometry of the viewport causes additional network traffic, this implies that *lazy-loaded* elements are present.
- eBay's shopping cart uses *lazy-loading*. Therefore we can exploit this web design to estimate the number of items in the shopping cart.
  - We can read DNS replies and isolate traffic from eBay's image content delivery network (CDN).

Counting eBay Cart Items





Defences

- To prevent against these types of attacks two conditions must be satisfied:
  - Network traffic patterns must be *indistinguishable* from each other.
  - The user and web application should immediately be made aware of network traffic tampering (eg. blocking requests).

Defences

- Consider the implications of strict adherence to the condition that *network traffic patterns must be indistinguishable from each other*:
  - All web requests must be padded to match the size of the largest web request.
  - *Noise* traffic must be generated to obscure the presence of real-time events.
- Not suitable as a general-purpose fix as this would result in intolerable performance overheads for many applications.

Defences

- At the current state of research an *application-specific threat model* and a *cost-benefit* approach are required.
  - Does revealing what page was loaded violate the security requirements?
  - Does revealing the timing of user events violate the security requirements?
  - Etc...
- The model-driven software development process can help.
  - Assign a property that all pages of a class be of the same size.
  - Assign a property that the timing of network events *must* follow a predefined schedule.
  - Etc...

Conclusion

- We have discussed the theory and implementation for side-channel detection tools capable of detecting the following types of network traffic based side-channels in web applications:
  - Response dependant page loads
  - Real-time feedback systems
  - Lazy-loading of web resources
- We have determined these vulnerable designs to be present in modern web applications.
- We have released all source code and example network traffic capture files on our GitHub page.

Future Work

- Work with model-driven software development to enforce side-channel resistance properties such as those discussed in the *defences* section.
- Expand the future model-driven development work to include non-web network services such as remote shells (SSH) or control of IoT devices.

Thank you!

Any questions?

https://github.com/uoitdnalab/networksidechannel