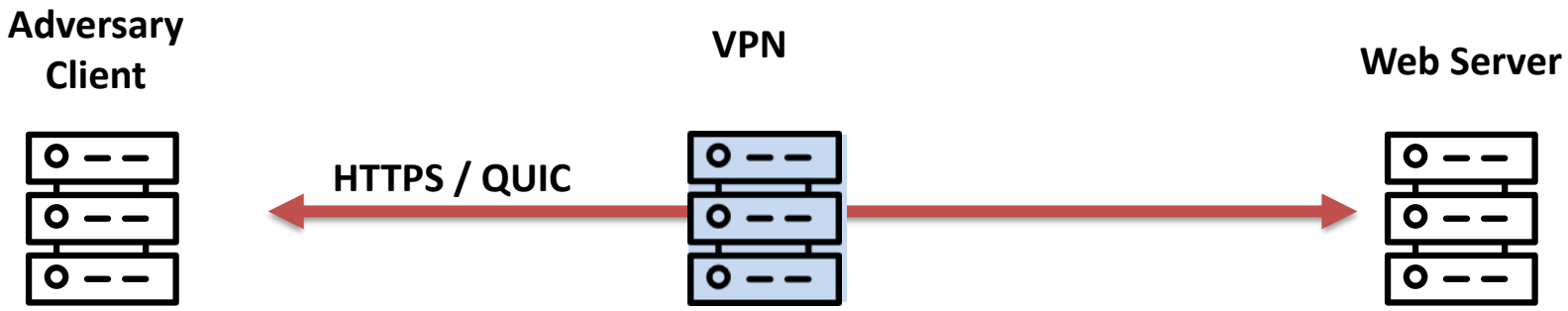
A Framework for Detecting Secure Web Traffic Over VPNs: HTTPS and QUIC



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Outline

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2. Secure HTTP Protocols
3. Solution Based on Discrepancy of RTT
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   b. QUIC
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VPNs were once the standard for remote access, but today they are one of the most exploited entry points for cyberattacks.

1. Introduction

- Typically, an anonymity network (VPN or TOR) is used to hide the identity of the hacker.
- There are several recent attacks using anonymity networks and geo-spoofing.
  - Workers loyal to North Korea have infiltrated global organizations via a fraudulent remote work scheme, violating international sanctions and posing cybersecurity risks to employers.
- Geo-spoofing allows attackers to appear in trusted regions.
- Avoiding Geo-Restriction to access services from permitted jurisdictions.

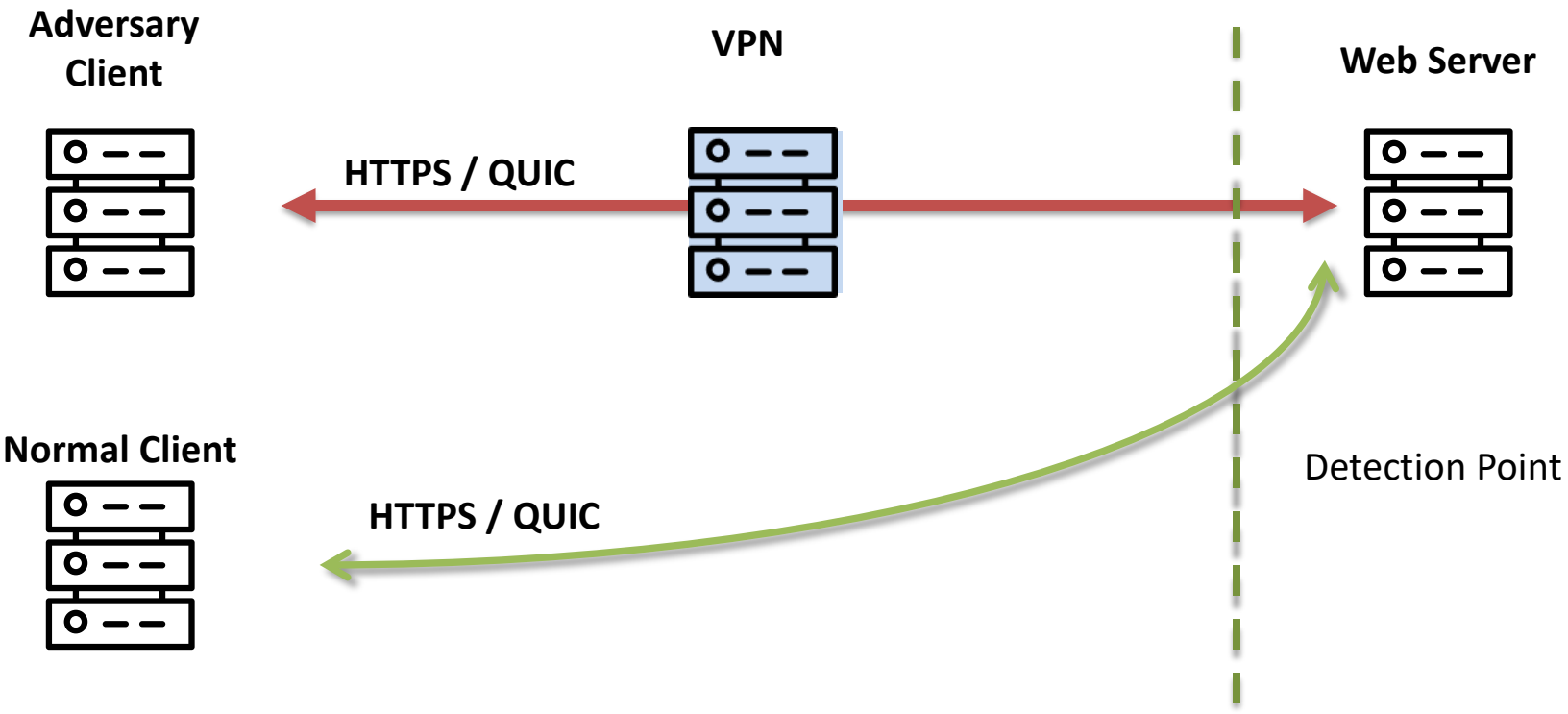
Laptop Farm

Cyber Security | Cyber Security News

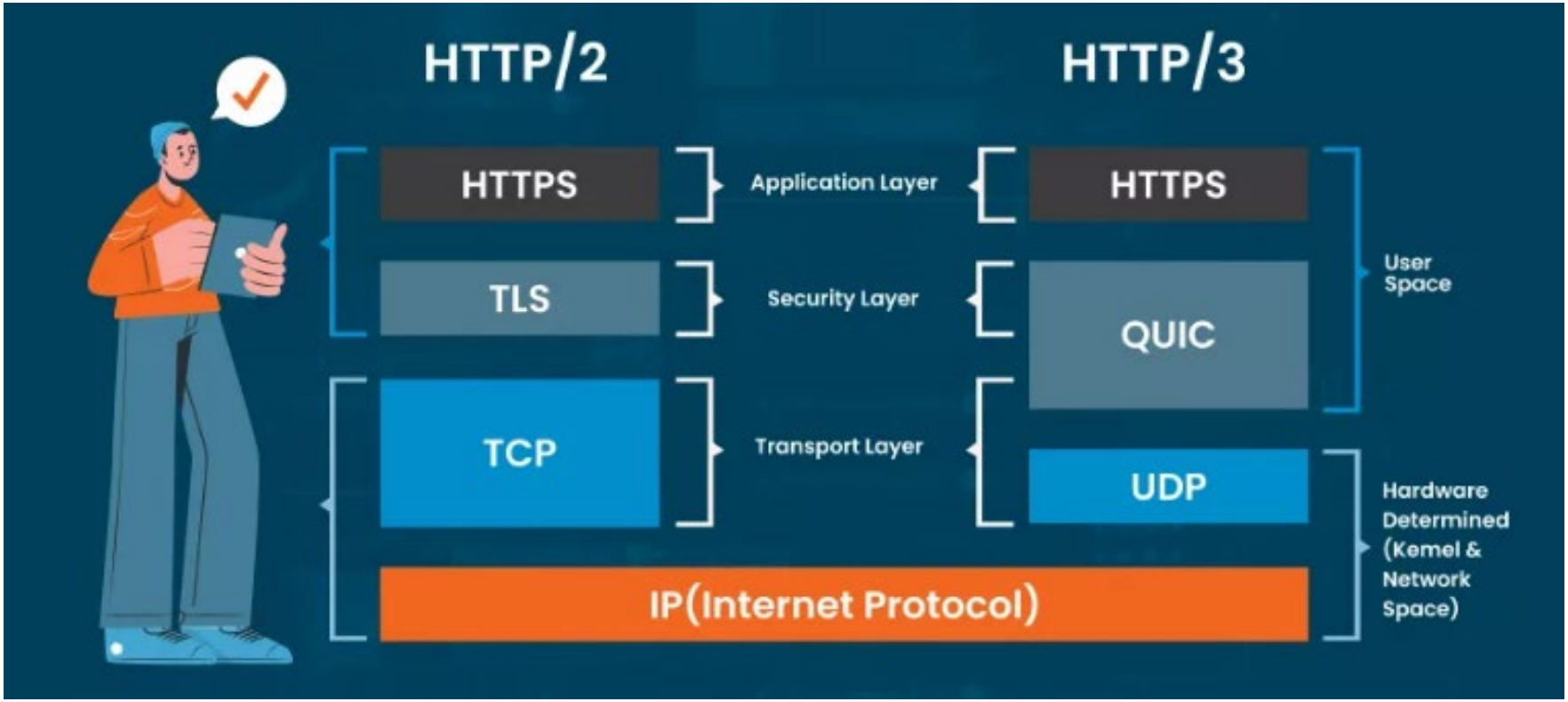
U.S. DOJ and Microsoft Dismantle 29 Laptop Farms and 200 Computers Used by North Korean IT Workers

By **Kaaviva** - Iulv 1. 2025

Classification Problem



2. Secure HTTP Protocols



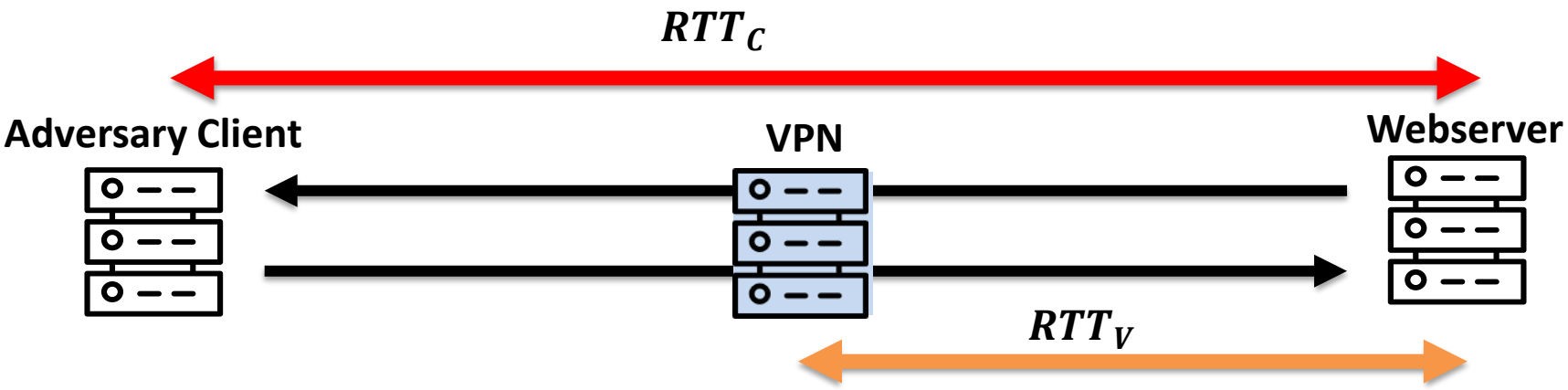
https://cheapsslweb.com/blog/what-are-quic-and-http-3-difference-between-http-3-and-http-2/

Virtual Private Network (VPN)

- Our worst-case assumption:
  - Unlike the TOR network, for which there is only one, a VPN can be installed on a "private" machine, making it stealthy.
  - Turning off all network contacts of the VPN, such as ping and traceroute.
- An active probe can be initiated, which can find a reasonable estimate of the round-trip time (RTT).
  - Use traceroute to the nearest neighbor.

RTT Discrepancy Ratio

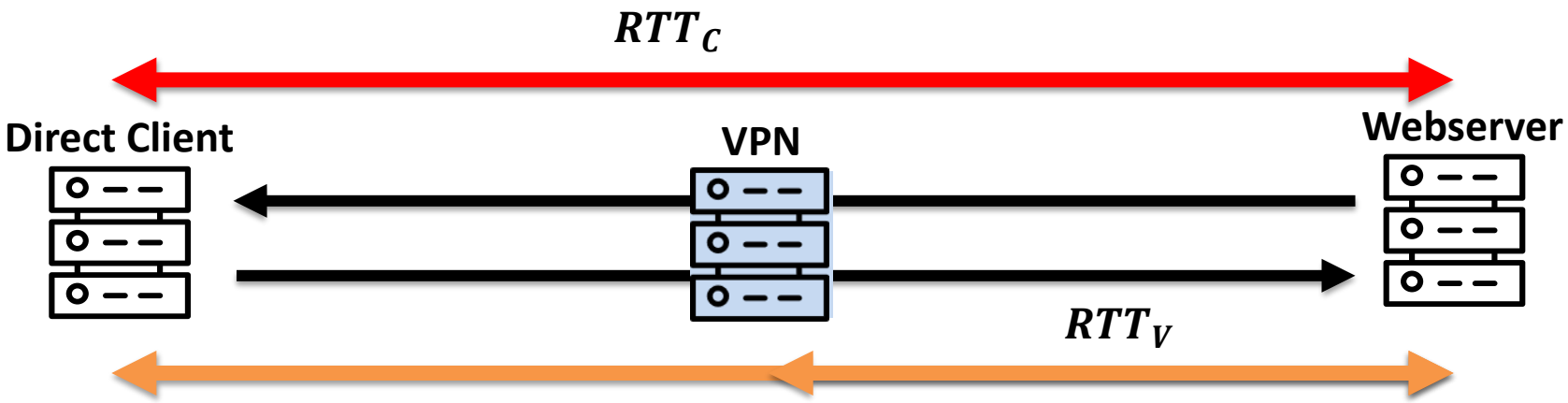
- RTT_C: RTT between the web server and the client
- RTT_V: RTT between the web server and the VPN



- With VPN: $\frac{RTT_V}{RTT_c} << 1$

RTT Discrepancy Ratio

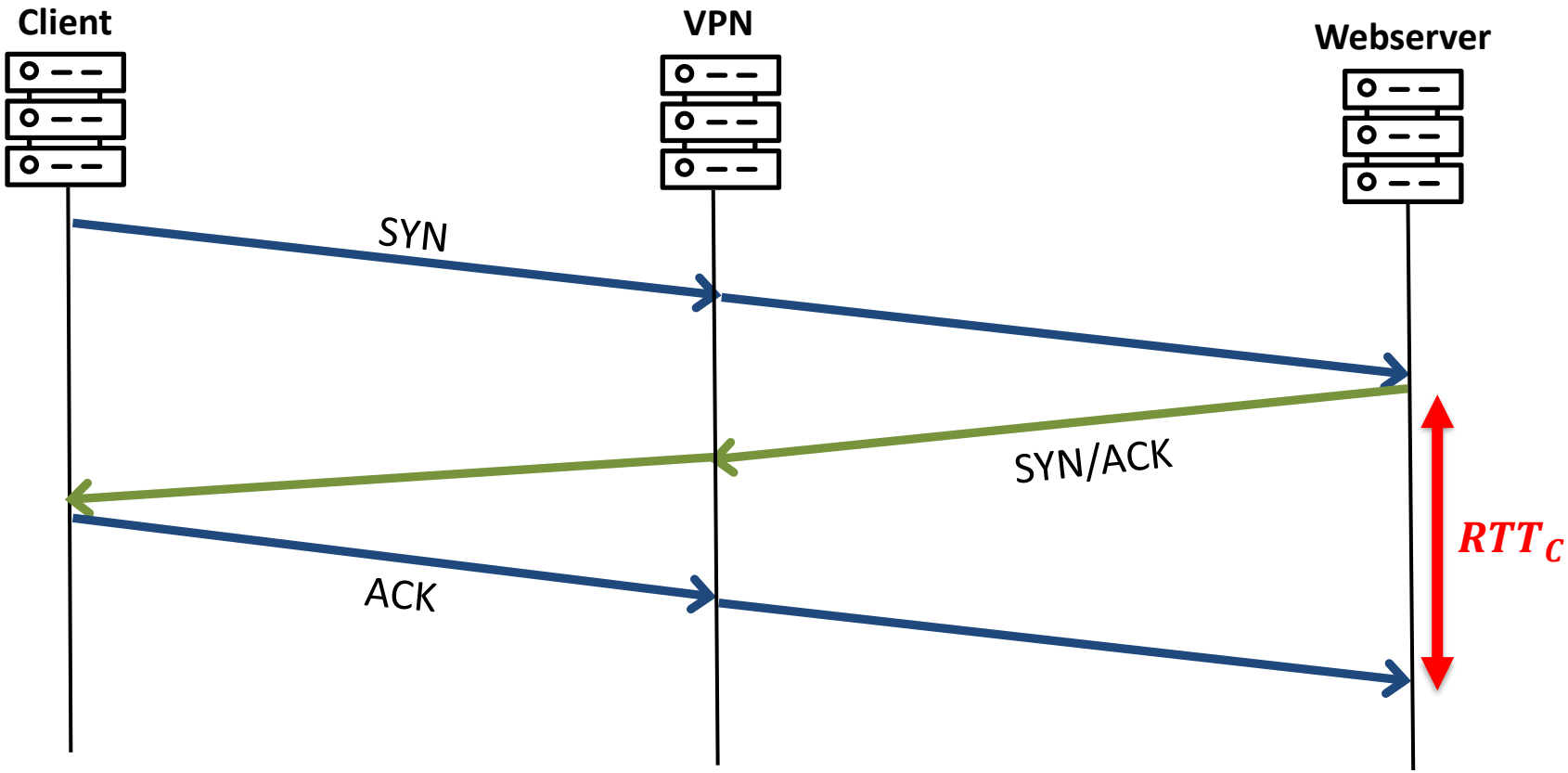
- The ratio can be used to discriminate whether there is a VPN.



- Without VPN: $\frac{RTT_V}{RTT_C} \sim 1$

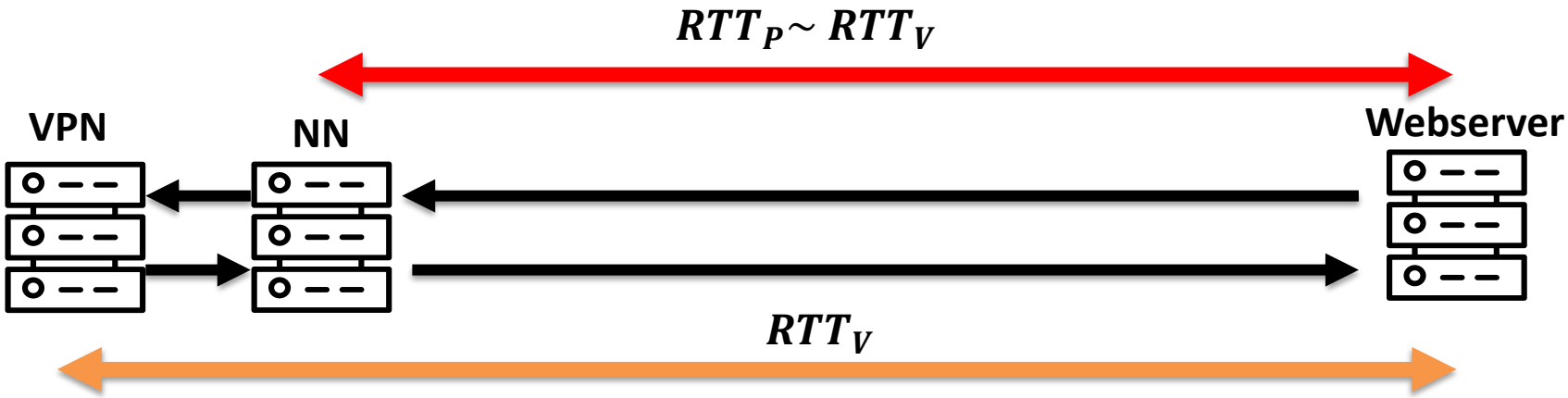
Calculating RTT_C

- The TCP three-way handshake provided the RTT_C on the web server (w/ or w/o VPN).



Active Probe for RTT_V

- To calculate the RTT, we need an ACK from the VPN. If the VPN does not send an ACK, we cannot measure the RTT_V.
- If a traceroute does not reach the VPN, it will get to the nearest neighbor.
- Experiment shows that the difference is minimal.

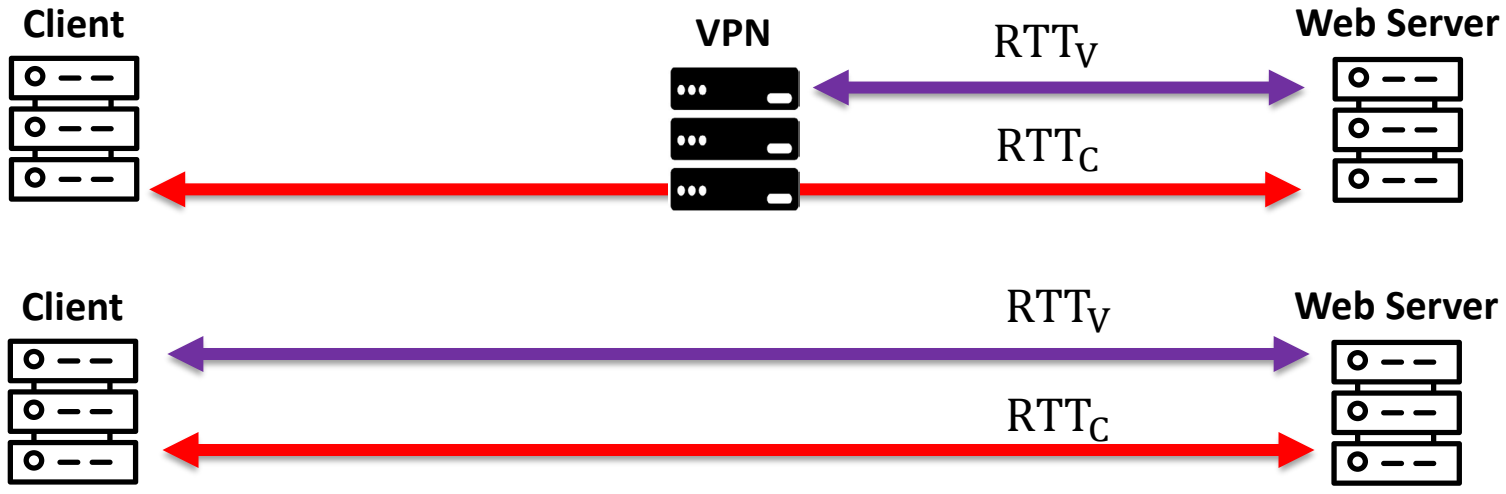


VPN Configurations

- In most VPN systems, a proxy (or a load balancer) is deployed before the VPN backend.
  - This will alter the TCP three-way handshake behaviors so that the proxy does not reflect end-to-end latency between the client and the web server
  - QUIC is not a TCP-based protocol; thus, the proxy has no impact on QUIC.

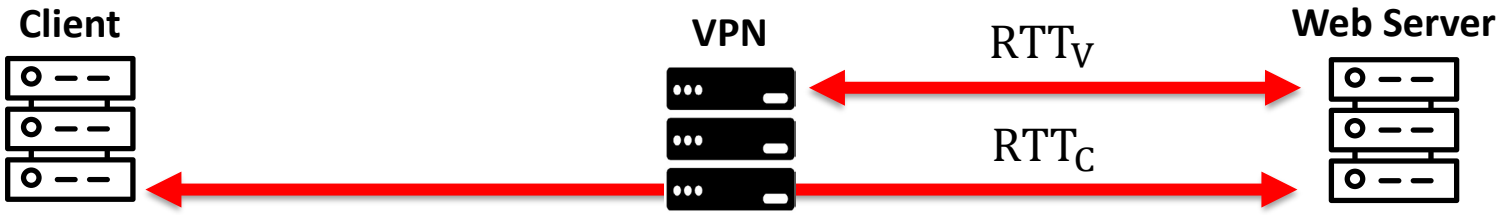
3. Solution Based on Discrepancy

- Question: Did the client connect to the web through a VPN?
- Our solution is based on the discrepancy of RTT: RTT_V vs. RTT_C
- How do we measure the two values?



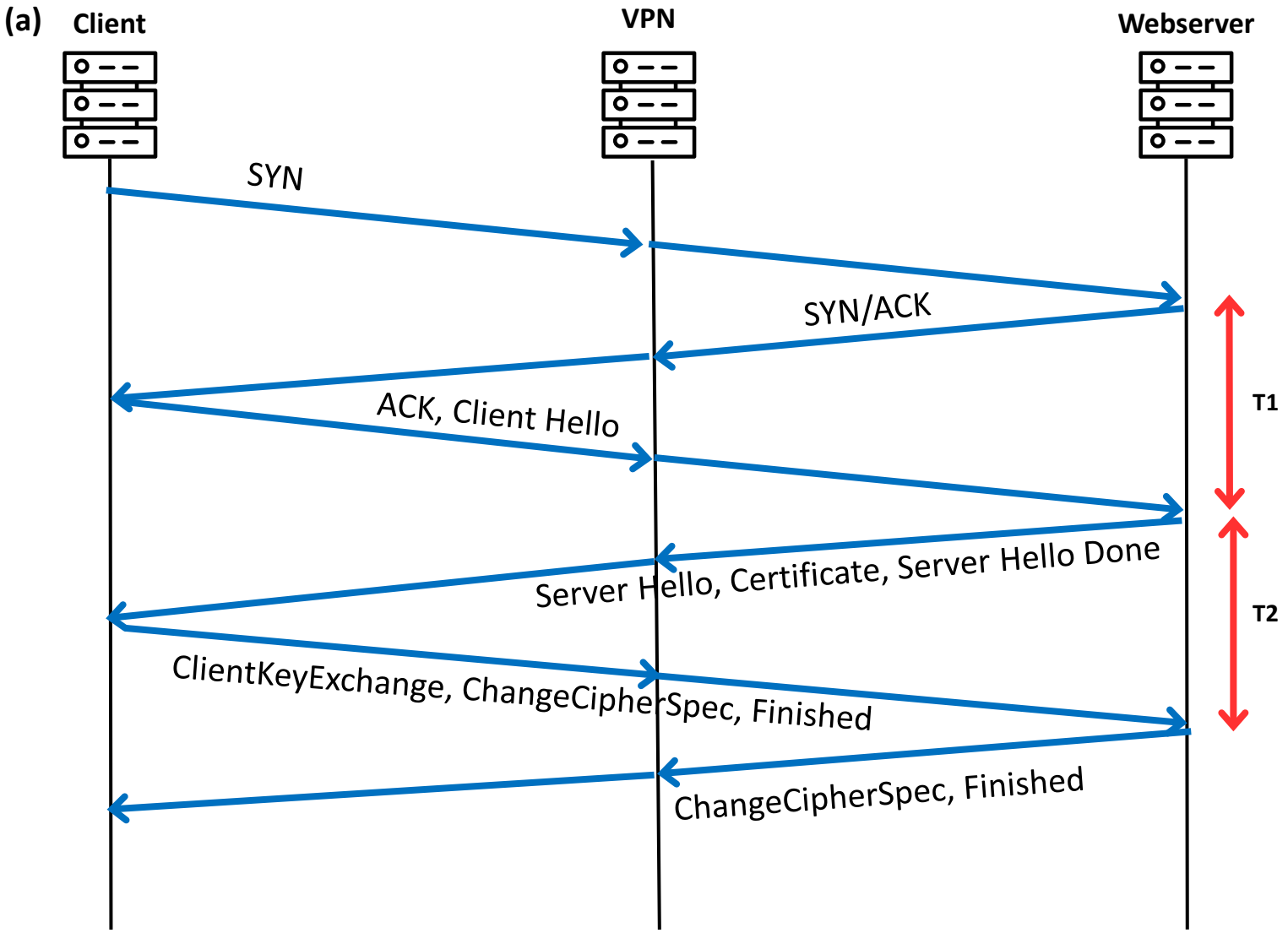
(a) HTTPS

- All we need to do is to find a good estimation of RTT_V and RTT_C
  - We can obtain RTT_C from TCP and HTTPS protocol handshake.
  - We can use the Active Probe to find an approximate value of $RTT_P \approx RTT_V$.

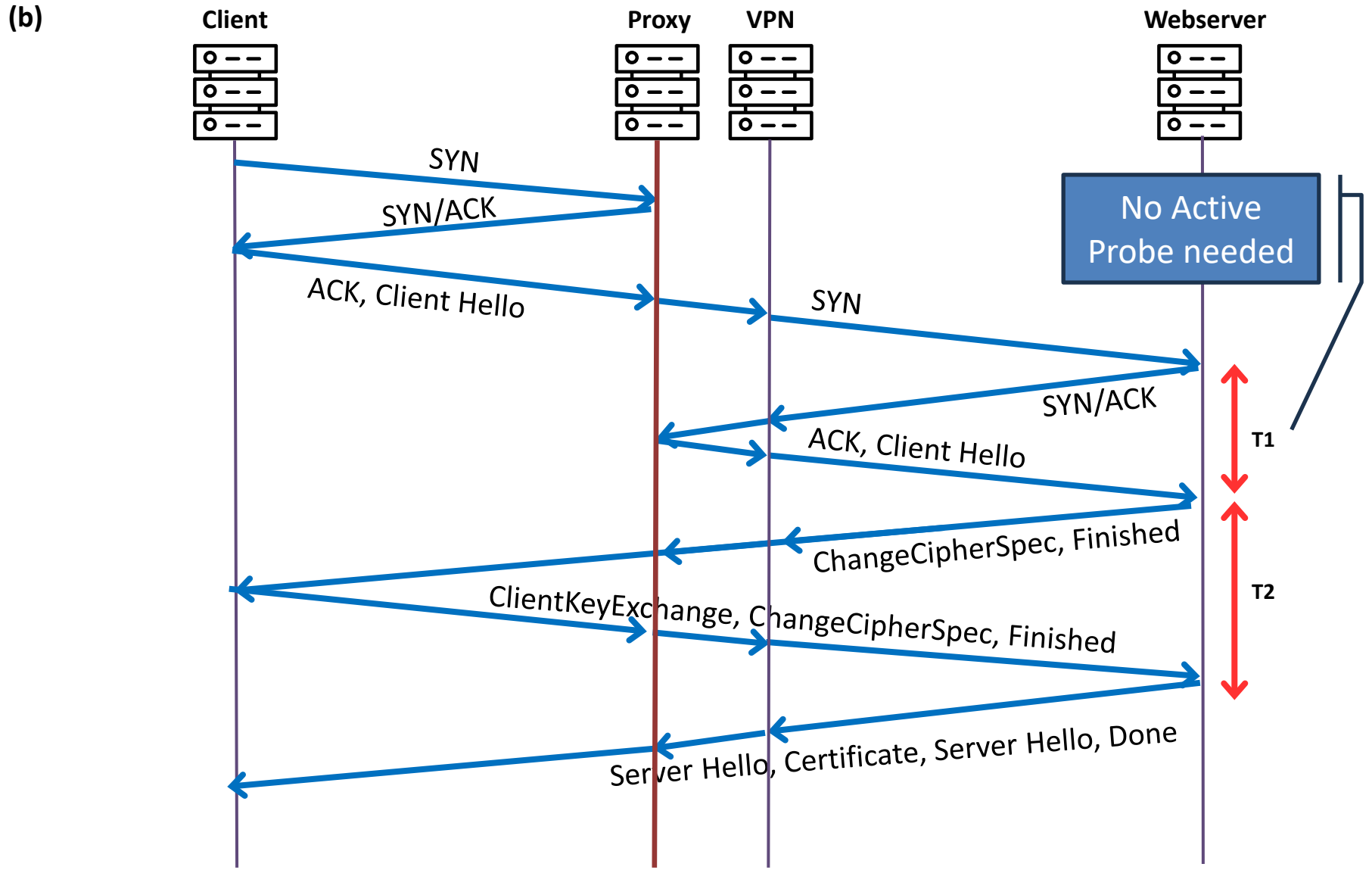


- However, VPN configuration complicated the algorithm
  - Stand-alone VPN
  - VPN with a Proxy server

(a.1) HTTPS VPN


(a)
Client
VPN
Webserver
SYN
SYN/ACK
ACK, Client Hello
Server Hello, Certificate, Server Hello Done
ClientKeyExchange, ChangeCipherSpec, Finished
ChangeCipherSpec, Finished
T1
T2

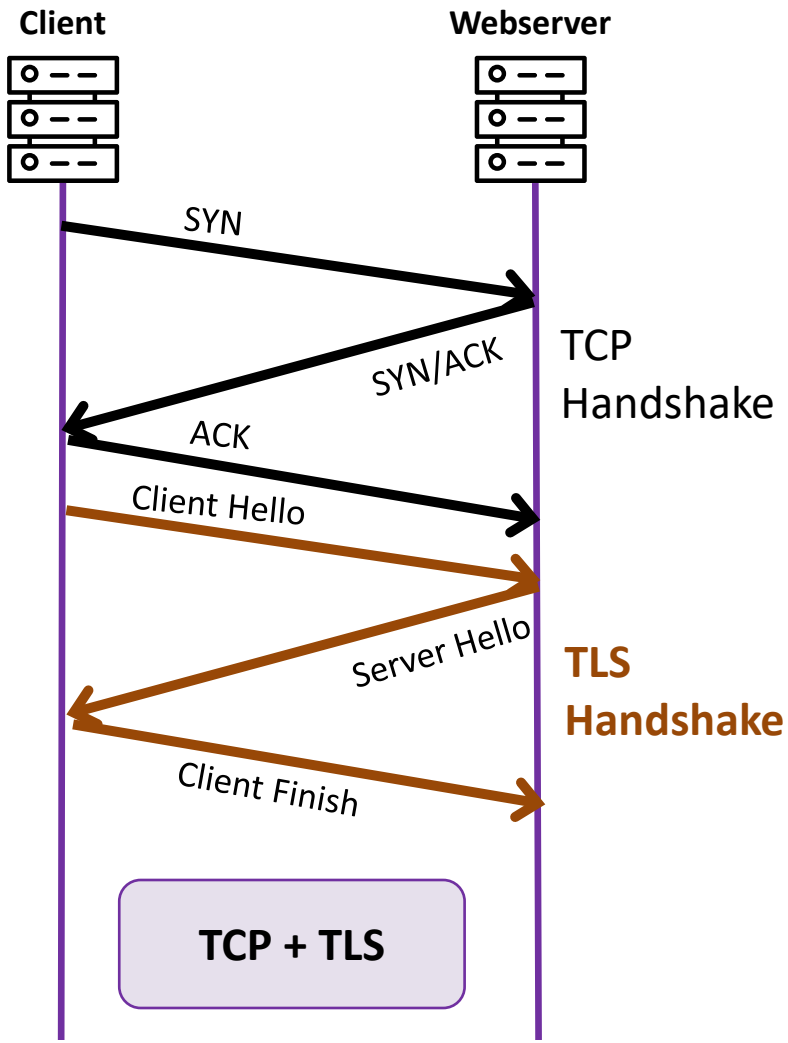
(a.2) HTTPS VPN w/ Proxy

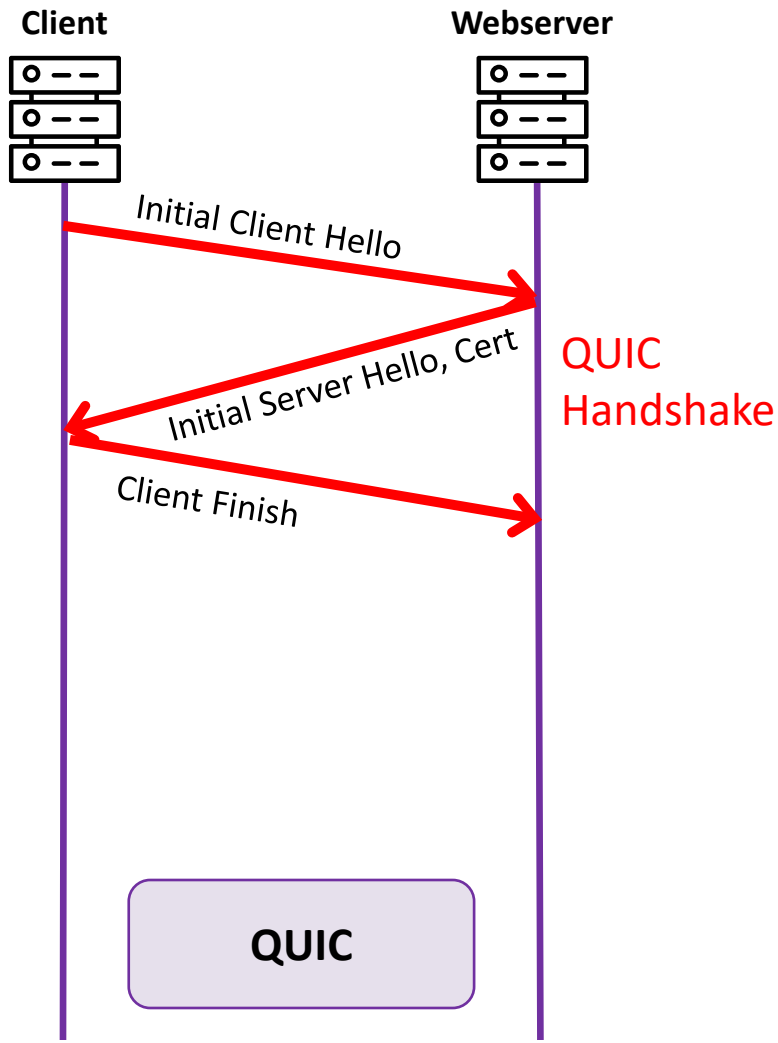


(b) QUIC

- QUIC stands for Quick UDP Internet Connections.
- QUIC effectively packs more application-level information into each UDP packet than HTTP/2 does into TCP packets. (Efficiency)
- The first successful connection between a QUIC client and server is always a 1-RTT handshake.
- Subsequent connections may be 0-RTT if the condition is right.

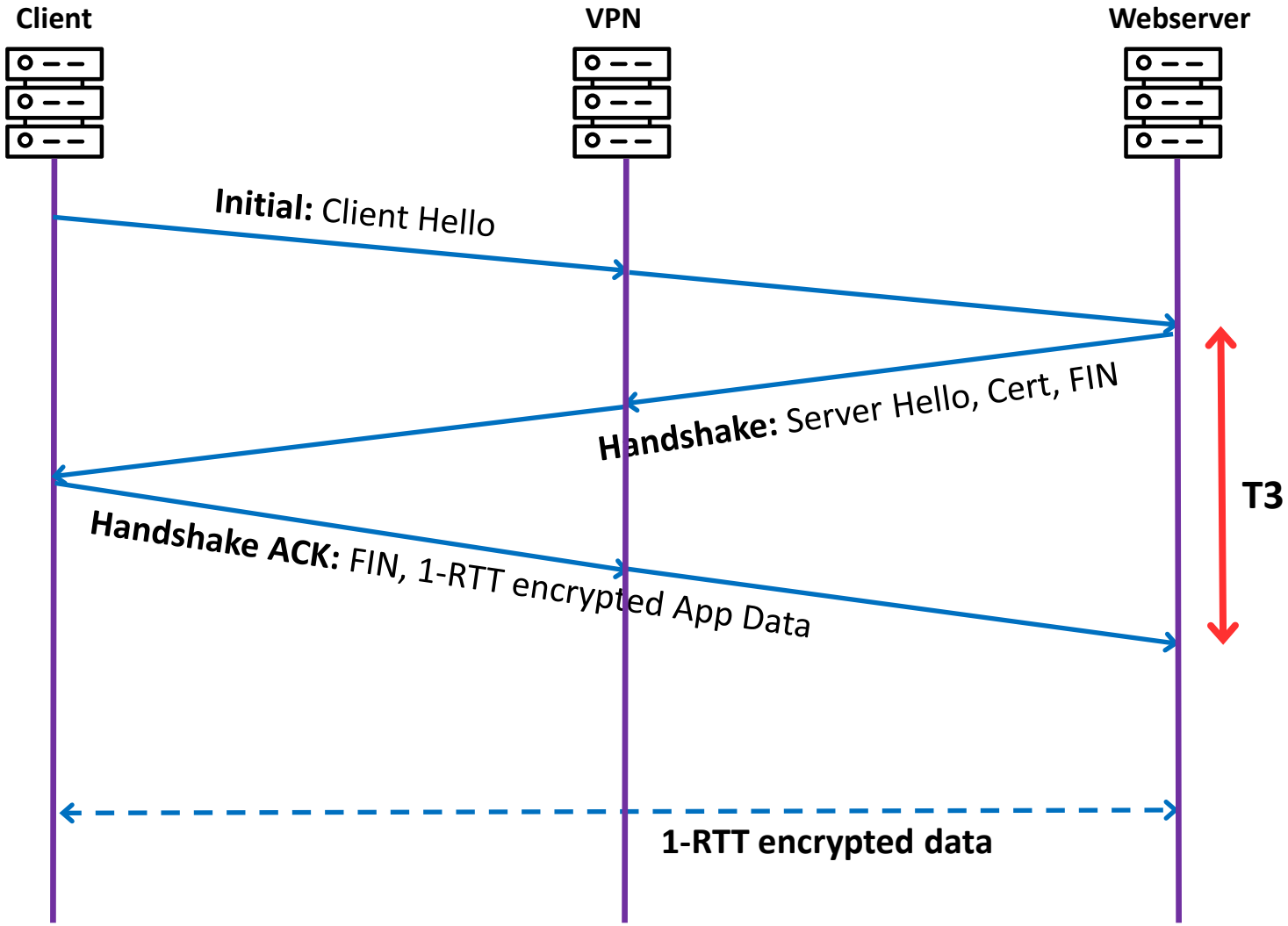
QUIC vs TCP+TLS





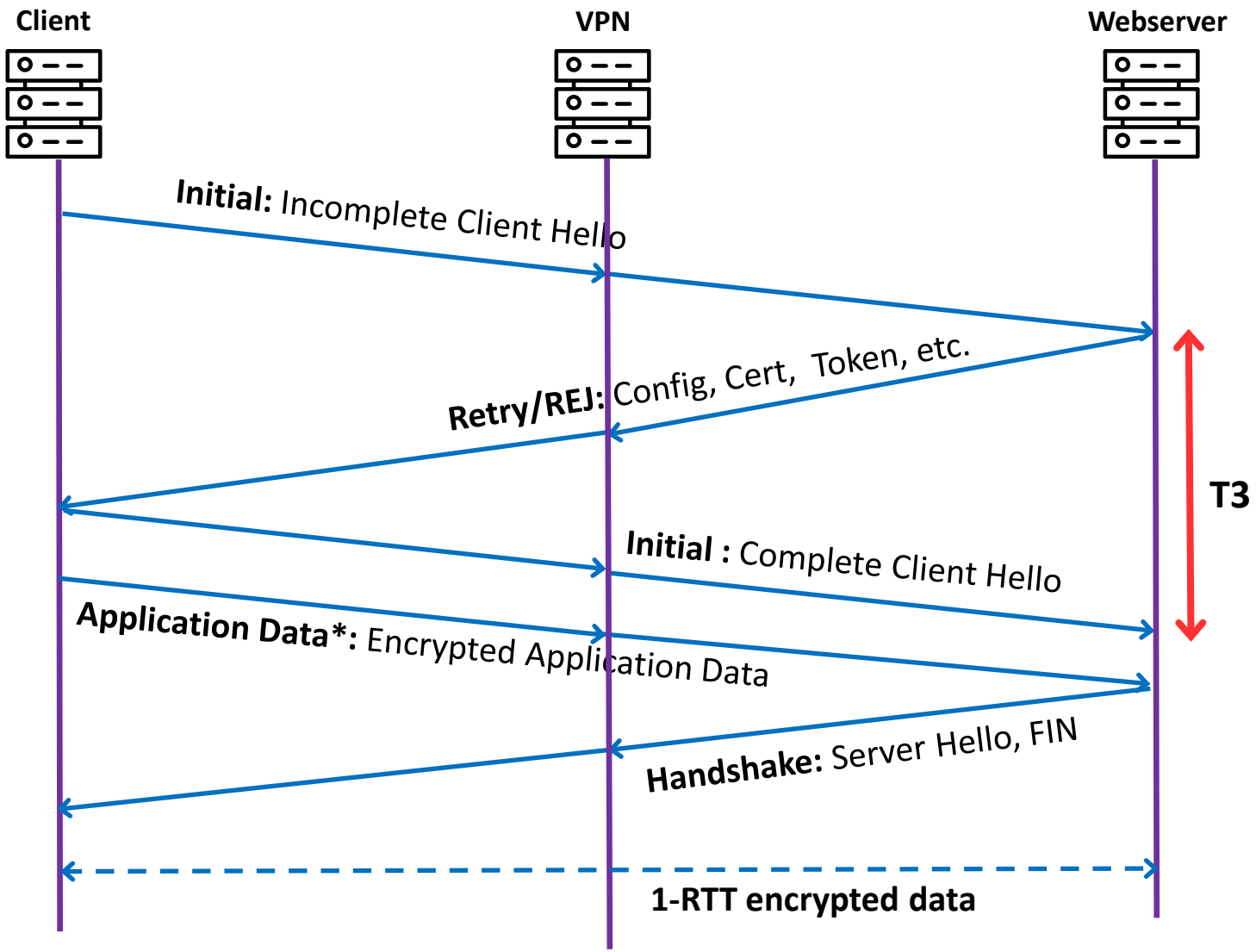
QUIC 1-RTT

(a) Standard 1-RTT QUIC handshake.



QUIC 1-RTT w/ Retry

(b) 1-RTT QUIC handshake with Retry.



Machine Learning Features

ML Attributes for HTTPS: (for w/ or w/o proxy)

- **T1**: RTT from the TCP three-way handshake
- **T2**: RTT from the TLS handshake
- **RTT_P**: RTT measured via traceroute-based active probing
- **RTT_P/T1**: discrepancy ratio between RTT_P and T1
- **RTT_P/T2**: discrepancy ratio between RTT_P and T2

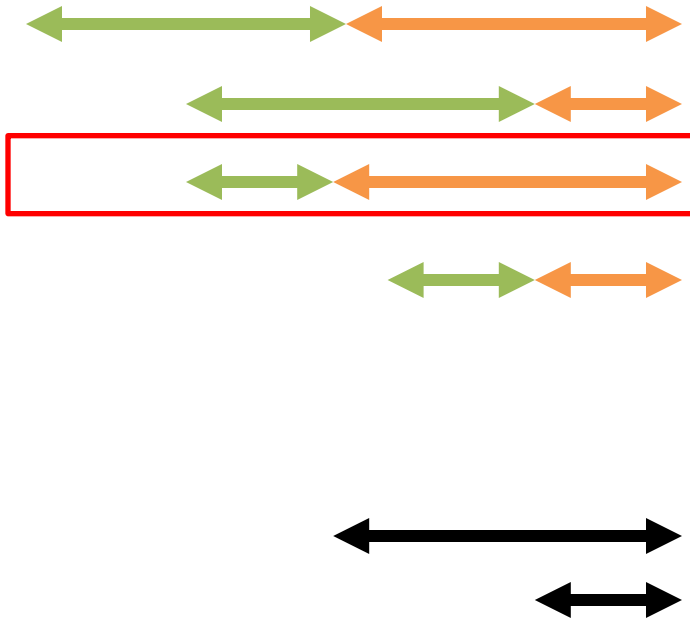
ML Attributes for QUIC:

- **T3:** TLS-layer RTT derived from the QUIC handshake
- **RTT_P:** RTT measured via traceroute-based active probing
- **RTT_P/T3**: discrepancy ratio between RTT_P and T3.

- Note that both absolute and relative numbers are used.

4. Validation and Performance

- Using the RTT ratio may be sensitive to slight variations in RTTs.
- We tested four extreme cases of connection ratios.



VPN		
Config Type	# Config	# Data Point
Long-Long	60	300
Long-Short	60	300
Short-Long	120	600
Short-Short	60	300
Total	300	1500

Direct Connection		
Config Type	# Config	# Data Point
Long	150	750
Short	150	750
Total	300	1500

Classification Accuracy

HTTPS

ML Model		Accuracy	F1-score	Precision	Recall
SVM	RBF	0.9910	0.9909	0.9946	0.9873
	Linear	**0.9943**	**0.9943**	**0.9960**	**0.9926**
	Poly	0.9853	0.9853	0.9867	0.9840
	Sigmoid	0.8997	0.8989	0.9041	0.8943
Random Forest		**0.9963**	**0.9963**	**0.9973**	**0.9953**
Naïve Bayes		0.9890	0.9775	0.9925	0.9630
Logistic Regre.		0.9897	0.9777	0.9923	0.9637
Neural Net		**0.9967**	**0.9967**	**0.9980**	**0.9967**
XGBoost		**0.9963**	**0.9963**	**0.9980**	**0.9947**

Classification Accuracy

QUIC (HTTP/3)

ML Model		Accuracy	F1-score	Precision	Recall
SVM	RBF	0.9446	0.9428	0.9428	0.9127
	Linear	**0.9355**	**0.9320**	**0.9824**	**0.8873**
	Poly	0.9151	0.9131	0.9466	0.8842
	Sigmoid	0.8555	0.8536	0.8797	0.8315
Random Forest		**0.9553**	**0.9549**	**0.9638**	**0.9467**
Naïve Bayes		0.8890	0.8685	0.9265	0.8175
Logistic Regre.		0.8903	0.8685	0.9280	0.8163
Neural Net		**0.9480**	**0.9471**	**0.9661**	**0.9293**
XGBoost		**0.9527**	**0.9525**	**0.9419**	**0.9733**

5. Conclusion

- This paper developed an innovative algorithm that detects secure HTTP traffic through a VPN, all while keeping the VPN server's identity under wraps.
  - Different VPN configuration (w/ or w/o proxy)
  - Different Secure HTTP protocol (HTTPS vs QUIC)
- The algorithm is real-time; it completes the detection before any application data is transmitted.
- We found very high detection rates on selected extreme cases using several ML algorithms. The testing was done using several commercial VPN servers.
- The detection algorithm runs on the web server; thus, it can detect geo-spoofing, prevent copyright and licensing infringement, but is not likely to be used to impose censorship.

Thank You

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