Framework for testing Open Quantum Safe for TLS Servers

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Abstract

This research aims to analyse if the TLS servers in Mauritius are correctly implemented for easy mitigation to Quantum Safe Cryptography. Since Quantum Computing is becoming more advance, we need to secure our online activities to prevent malicious actors from leveraging it against us. The framework, which is written in python, is a versatile tool that provide an effective method for countries or organisations to test their own networks. The methodology involves fetching a list of IP addresses corresponding to a country of organisation which will be filtered for open port 443. For faster execution time, we leverage the use of parallel processing. Finally, the filtered IP addresses will be analysed for the TLDR bug anomaly. This rigorous approach allows for an effective method to determine the effectiveness of the servers and assess the level of security against the impending threats of quantum computing. The code for this project is available at GitHub[1].

Introduction

In this fast-paced world, where advancement in technology is exponential and the tools we utilise are fast and efficient, our safety on the internet is at risk. One of such tools is Quantum computing, which theoretically has the potential to crack any classical encryption. As stated by Shaller et al., 2023, Public-key Cryptosystems such as Rivest-Shamir-Adleman (RSA), Diffie-Hellman (DH) and Elliptic Curve (EC) Cryptosystems, relies on the difficult of the Integer factor or the Discrete Logarithm problem. These cryptosystems are currently in use on the internet as a means to secure our online activity. A quantum computer using Shor's algorithm can easily break these cryptosystems in polynomial time.

[1] https://github.com/AtishJoottun/Tldr_fail_testing

Below is a data captured by Dr. Michele Mosca and Dr. Marco Piani, 2023 showcasing their survey.

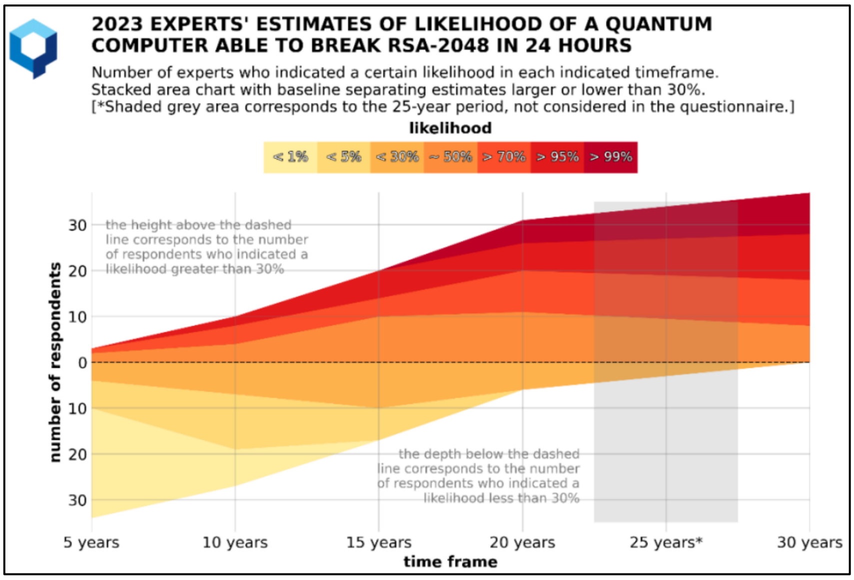


Figure 1: Experts' estimates of likelihood of a quantum computer breaking RSA-2028 in 24 Hours by Dr. Michele Mosca and Dr. Marco Piani, 2023

Currently this is only a theoretical level of a quantum computing, but we are closer than ever to realise such a technology. This analysis covers how can we protect our TLS servers from quantum computers. The chosen place to run our investigation is the Island of Mauritius as it has a growing technology industry.

There are already some nations like US and Singapore that are mitigating to a post quantum cryptography. according to the Monetary Authority of Singapore, 2024, Singapore is preparing to mitigate to a post quantum cryptography for the Financial Institution in Singapore as to reduce impact of quantum attacks to their IT system.

How does a Quantum computer work?

A Quantum computer takes advantages of two quantum mechanical phenomena such as: Quantum superposition and Quantum entanglement, which make it much faster than a classical computer. A quantum computer uses a quantum bit (qubit) to represent a unit of information. Unlike classical bit which can have either 1 or 0, a qubit is known as a two-state quantum-mechanical system, meaning it has 2 bits. As stated by Ladd et al., 2010, "A qubit is a quantum system with two states". This property allows the qubit to have 4 possible combinations at once.

According to Barenco et al., 1996, after the discovery of a fast quantum factorisation algorithm, it was observed that error control plays a key role to ensure the efficiency of the quantum computation. A qubit which is not in a perfectly isolated environment will suffer from noise and errors which will disrupt the information encoded in it. We could reduce the error by constructing a logical qubit, which is a collection of physical qubits. As Fowler et al., 2012 wrote, "It is however possible to construct a logical qubit from a collection of physical qubits such that the logical qubit performs much better than the individual physical qubits".

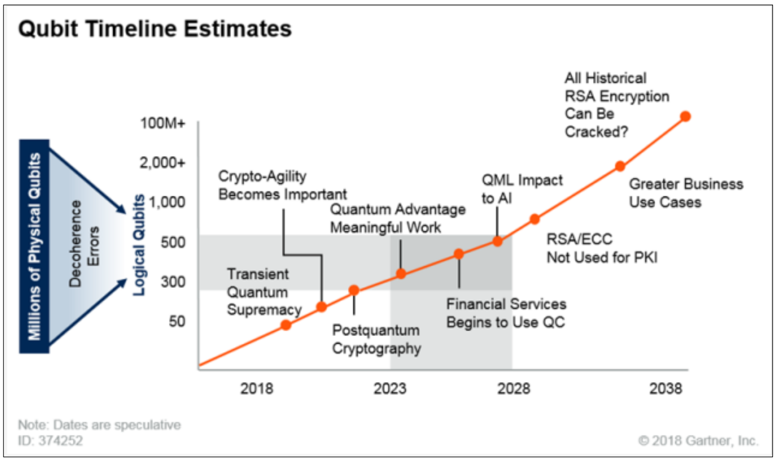


Figure 2: Qubit Timeline By Quantum Computing Timeline by Gartner | Tmilinovic's Blog, nd

The current holder for the largest number of qubits is IBM. As stated by Patra et al., 2023, IBM are continuously presenting an increasingly powerful quantum computer each year such as: IBM Eagle's at 2021 with 127 qubits, IBM Osprey's with 443 qubits in 2022 and finally, IBM Condor's breaking the 1000 qubits mark, with a record holder of 1121 qubits in 2023. Although IBM Condor is very powerful, it is still in an experimental phase. These three quantum computers are currently between the most powerful quantum machine in the world.

When a much more powerful quantum computer will arise, the IT infrastructure will be completely at risk. To avoid such danger, we could use tools such as quantum safe cryptography, which are algorithms which are made to resist quantum computing. The mathematics behind these types of algorithms makes it hard for even a quantum computer to crack it. A few of this quantum safe cryptography are Kyber and NTRU. National Institute of Standards and Technology, no date, (NIST) is amid of choosing a candidate to standardise the post-Quantum cryptography.

In TLS servers, the latest version of TLS, TLSv1.3 can use Open Quantum Safe, no date, which is an open-source project with the goal to transition to a quantum-resistant cryptography.

What is the TLDR Bug?

Some misconfigured servers or the TLS middle boxes rejects the connections made with post-Quantum Secure Cryptography rather than negotiating for a classical cryptography.

Why does this happen?

A TLS *ClientHello* that uses a post-quantum cryptography will have a larger size than a TLS *ClientHello* that uses classical cryptography. Due to their large size, they exceed the packet transmission limit and needs to be sent into multiple packets. However, there maybe a chance that a TLS server which has not been properly implemented will not read the large *ClientHello* fully. Thus, making the server to terminate that connection.

This bug was documented by David Benjamin, no date. In his website, he explained the bug in great details. David Benjamin, also made a script that checks if the TLS servers have been correctly implemented.

How does the TLDR script works?

The script works into four main parts: send a large message to the client, known as a *clientHello* at once, send the same large *ClientHello* in 2 packets, send a small TLS *clientHello* at once, and finally, sends the same small *ClientHello* in 2 packets. After each send, the script waits for an Serverhello packet. If the serverhello packet did not start with a certain pattern or the connection was disconnected, we deemed the server has buggy.

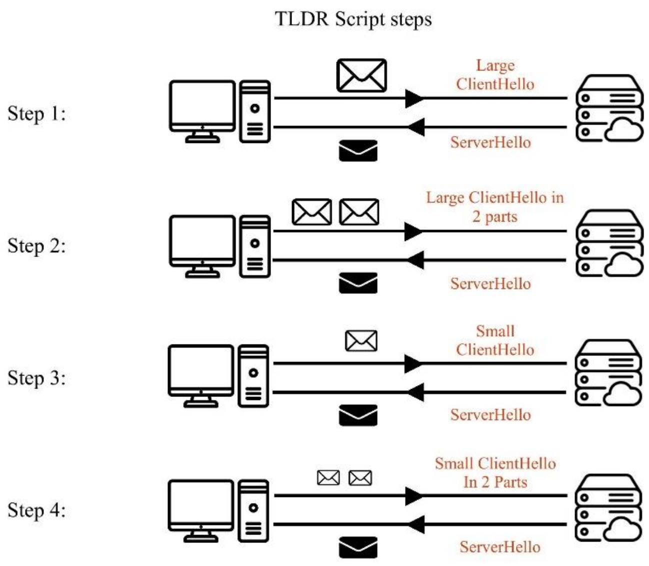


Figure 3: TLDR script.

Methodology

The methodology used for this paper is a simple filtering to extract the correct usable data since the initial starting point has a lot of data that are redundant for the TLDR script to test. Below is a simple overview of the methodology.

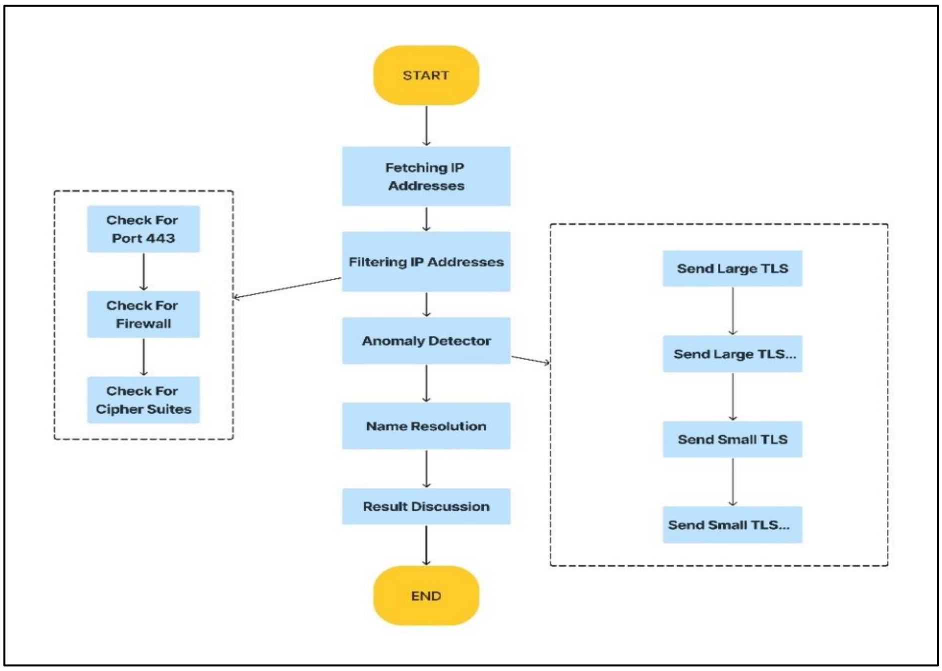


Figure 4: Methodology Used

Getting the IPs for Mauritius

Each Country in the world has a range of IP addresses that they are allowed to use. They are assigned by The IANA, Internet Assigned Numbers Authority, no date, which is a standard organisation that oversees global IP addresses and other Internet-Protocol related to Internet Service Provider (ISP). Each country gets their IP from either the Local Internet Registry (LIR) or Regional Internet Registry (RIR). Mauritius' registry is AFRINIC the Region Internet Registry (RIR) for Africa - AFRINIC - Regional Internet Registry for Africa, no date.

IP2Location, 2024 was used to identify IP address blocks assigned to Mauritius, totalling **6,482,688** addresses across **543 ranges**. Starting and ending IP addresses for each range, along with corresponding counts, were extracted into an Excel spreadsheet. A custom script shown below was then employed to generate a comprehensive list of individual IP addresses within these ranges by systematically incrementing each range based on its allocated count.

```
FUNCTION get_list_of_ip_addresses_from_file()
    ip_addresses = []
    range_of_ip_addresses <- open("range_of_ip_addresses.csv")

    FOR i <- 0 TO LENGTH(range_of_ip_addresses) - 1
        start_ip <- range_of_ip_addresses.start_ip
        ip_count <- range_of_ip_addresses.ip_count

        FOR j <- 0 TO ip_count
            incremented_ip_address <- increment_ip_by(start_ip, j)
            ip_addresses.append(incremented_ip_address)
        NEXT j

    NEXT i

    RETURN ip_addresses
ENDFUNCTION
```

Scalable Data Processing

Recognizing the computational demands of processing a 6-million-entry IP address list and anticipating future large-scale datasets, we implemented a multiprocessing approach in Python for enhanced efficiency. Our custom script uses multiprocessing to distribute workloads across multiple processes. Flexibility is achieved by taking the *number_of_processes* as a parameter, which should divide evenly into the size of the data list. This script design also supports modularity, allowing users to define custom worker functions to match the specific processing needs of any list type.

```
FUNCTION start_multiprocessing(number_of_processes, worker_function,
return_processing_function, *additional_arguments)

    # Create a shared data structure for process communication
    shared_dictionary <- create_shared_dictionary()

    process_list = []
    FOR i <- 0 TO number_of_processes - 1
        process <- create_process(worker_function, (i,
shared_dictionary, number_of_processes, return_dictionary,
additional_arguments))
        process_list.append(process)
        start_process(process)
    ENDFOR

    # Wait for all processes to finish
    FOR process IN process_list
        wait_for_process_completion(process)
    ENDFOR

    # Process the results from the shared dictionary
    result <- return_processing_function(shared_dictionary)
    RETURN result
ENDFUNCTION
```

IP Address Validation and Port Filtering

The initial list of IP addresses was filtered to identify those with open port 443 (HTTPS). Filtering for open ports is essential because TLS connections, the focus of our analysis, can only be established on open ports. To achieve this, we employed the Nmap Scripting Engine (NSE). A custom NSE script was written to examine IP addresses and determine the state of port 443 (open, closed, or filtered).

The filtered list of IP addresses was further refined to distinguish between those likely protected by firewalls or middleboxes and those without such protection. An Nmap-based approach was utilized to assess the reachability of each IP address. IP addresses exhibiting a "filtered" status were classified as potentially behind a firewall or middlebox.

```
SUBROUTINE get_valid_ip_addresses(ip_addresses)
    valid_ip_file <- open_or_create("valid_ip_addresses.csv")

    FOR i <- 0 TO LENGTH(ip_addresses) - 1
        nse_port_result <- nse_check_ip_port(ip_addresses[i])
        nse_firewall_result <-nse_check_firewall(ip_addresses[i])

        IF nse_port_result == "open-443" AND
            nse_firewall_result <> "filtered" THEN

            OUTPUT ip_addresses[i] TO valid_ip_file

        ENDIF
    NEXT i
ENDSUBROUTINE
```

TLS server availability

Following the firewall classification step, we examined the remaining IP addresses to determine the presence of active TLS servers on port 443. This evaluation is crucial as our investigation focuses on the potential for the TLDR bug vulnerability, which specifically targets TLS configurations.

We employed OpenSSL, a widely used cryptographic toolkit, to attempt connections to port 443 on each IP address. Successful connections and the subsequent retrieval of cipher information signified an operational TLS server.

```
SUBROUTINE get_ip_addresses_with_tls_server(ip_addresses)
    ip_with_tls_server_file <-
open_or_create("ip_addresses_with_tls_server.csv")

    FOR i <- 0 TO LENGTH(ip_addresses) - 1
        ciphers <- get_ciphers(ip_addresses[i])

        IF LENGTH(ciphers) <> 0 THEN
            OUTPUT ip_addresses[i] TO ip_with_tls_server_file
        ENDIF
    NEXT i
ENDSUBROUTINE
```

This process refined our dataset to **3,576** IP addresses with confirmed TLS servers. These addresses constitute the core focus for subsequent analysis of susceptibility to the TLDR bug.

Testing the IPs for TLDR BUG

Having identified a vast pool of potential Mauritian TLS servers, our next step was to efficiently assess their vulnerability to the TLDR Bug. To automate this process and speed up analysis, we developed a script that integrated with David Benjamin's script. This solution iterated through the compiled list of open port 443 IP addresses that have been checked to not be behind firewall and have TLS enabled, running the David Benjamin's script on every entry.

```
SUBROUTINE test_tldr_bug(ip_addresses)
    ip_with_tldr_bug_file <-
open_or_create("ip_addresses_with_tldr_bug.csv")
    ip_without_tldr_bug_file <-
open_or_create("ip_addresses_without_tldr_bug.csv")

    FOR i <- 0 TO LENGTH(ip_addresses) - 1
        error <- run_tldr_script(ip_addresses[i]) #returns TRUE is tldr
bug found

        IF error = TRUE THEN
            OUTPUT ip_addresses[i] TO ip_with_tldr_bug_file
        ELSE
            OUTPUT ip_addresses[i] TO ip_without_tldr_bug_file
        ENDIF
    NEXT i
ENDSUBROUTINE
```

The resulting data was categorized as vulnerable or non-vulnerable and then exported to separate text files for further analysis.

Host Providers

To gain insights into the origins of the vulnerable websites, we investigated the network providers associated with their IP addresses. This involved utilizing a specialized Nmap tool that extracts network ownership information.

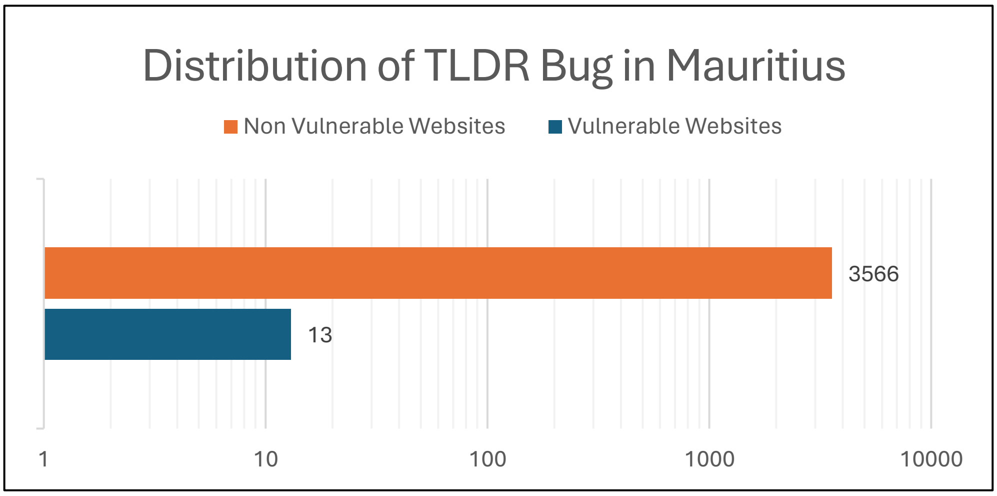
```
FUNCTION identify_ip_provider(ip_addresses)
    ip_address_with_provider <- [] #list of tuple

    FOR i <- 0 TO LENGTH(ip_addresses) - 1
        provider <- identify_ip_address(ip_addresses[i])
        ip_address_with_provider.append((ip_addresses[i], provider))
    NEXT i

    RETURN ip_address_with_provider
ENDFUNCTION
```

For each vulnerable IP address, the tool retrieved the "*netname*" which indicates the hosting provider or network the website belongs to. This information allowed us to classify vulnerable websites based on their providers.

Data Analysis and Representation

By employing these scripts for analysis, we were able to get valuable insight into the Vulnerability of Mauritius TLS servers and highlight the potential scope and impact of this critical vulnerability within the country's digital ecosystem.

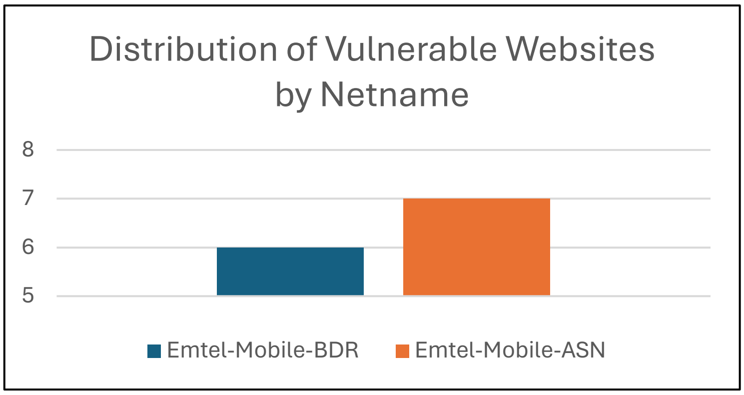
The graph below shows a compilation list of the data we have gathered.



Out of **6,482,688** IP addresses, a total of **3576** usable IP addresses were found which are available and not blocked by firewalls or any middlebox. Finally, out of the **3576** IP addresses, **3566** IP addresses were found to be non-vulnerable and **13** were found to be vulnerable.

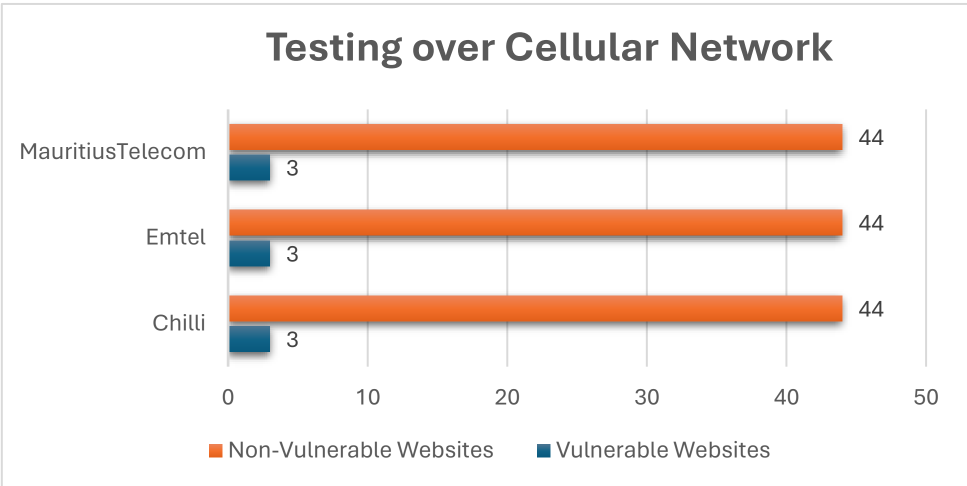
When analysing the 13 failed IPs, it was found that the IP addresses connected to the server but did not return any TLS ServerHello. Additionally, the TLS server did not terminate the connection. So, the 13 IP addresses were classified as Special Cases.

So the actual failure rate for the Island of Mauritius is 0%. Below is the classification of the special cases by the host provider.



TLDR Bug scanning over different Internet Service Providers

The bar chart below depicts the data analysed for the 47 most popular website in Mauritius which is found at Most Popular Websites In Mauritius, no date. The data is the same for the 3 ISPs. Our data is consistent across all the ISPs.



Since WI-FI was used for this analysis, there might be packet loss. The 3 website that failed have an expired domain name, meaning that the website no longer exists. Thus, the failure rate for the popular website is 0%.

Limitations

Due to restrictions of hardware, and lack of vantage point in Mauritius, we were not able to do a full scan on the most popular websites in Mauritius, at least top 300. We used laptops to run the programs which took lots of time to finish processing. We only scanned the IP Addresses in the WAN not on LANs, so we don't know the status of the internal IP addresses.

Improvements

One of the improvements that we could do is to get better resources. As for our vantage point, we could ask permission from companies to scan their internal network. This collaboration, will enable us to find the flaws that are hidden behind the TLS middle box or firewalls, thus ensuring a detailed scan of both the internal and external networks in Mauritius.

Conclusion

Since we are becoming more and more interconnected, there is a great necessity for safeguarding the digital infrastructure. This analysis demonstrates that Mauritius' servers are correctly implemented and safe to implement post quantum cryptography, implying that Mauritius can start a plan to transition to post quantum cryptography.

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