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SIT723 – Research Project A

Report on Peer-to-Peer model evaluation for protection against Advanced Persistent Threat (APT)

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Introduction and Motivation

Cyber-attack has been increasing rapidly. Most of the victims are targeted by the hacker using APT (Advanced Persistent Threat). This is a long and sophisticated attack process which required knowledge of the victim, type of tool and most importantly skill.

In this project, we are not going to investigate the entire APT attack. We will focus on the initial phase of the attack called recon. This is the first phase before any attack. Tool like nmap, tcpdump and wireshark can be used to collect traffic in the network. Even though, encryption is implemented, this is inadequate to keep the determined hacker from retrieving information. Information such as source & destination ip address, source & destination port and application version can still be retrieved from the traffic packet. This information gives enough information about the victim's system.

Literature Review

An Advanced Persistent Threat (APT) is defined as a sophisticated attack consisting of several steps carried out by the experienced and highly skilled actors with a great determination to achieve their goal (Brahim ID Messaoud, 2016). Most organizations have the primary security concern about the Advanced Persistent Threat (APT) towards their technical infrastructure which have the potential impact of serious damage to organizations from cybercriminals (Dev Bhatnagar, 2019). In fact, there is a significant risk to every organization due to the Advanced Persistent Threats (APT) because of the sophistication which allows attackers to bypass security systems and largely infiltrate the target network (Martin Ussath, 2016). The attack and the defence system to counter APTs must involve advanced planning and strategies like military operations. The current cyber-security-methodologies are not sufficient to adequately address APTs (Sun et al., 2020). In this Advanced Persistent Threat, the initial phase known as Recon is used to gather information about the target like employees, organization's IT infrastructure, assets, network and many more (Alshamrani et al., 2019). As communication is also an essential part and that consists of sensitive information, adversaries target these for meta-data about sender and receiver and other sensitive information. The traditional way of communication used to happen through a centralized node and that was exploited more often by attackers (Zhang et al., 2020).

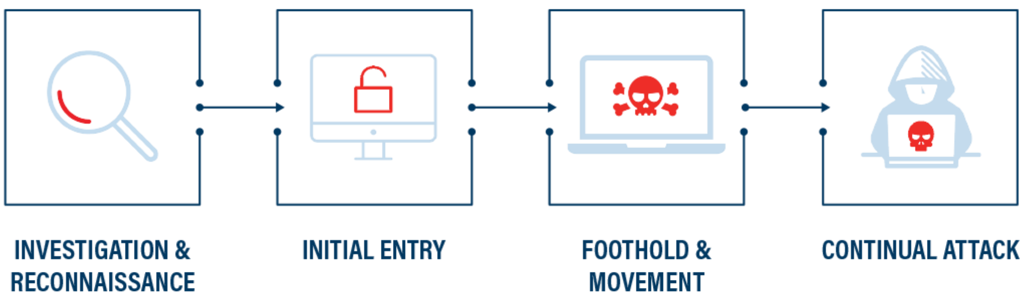


Figure 1-The phases of an advanced persistent threat (APT) (TEAM, 2019)

When it comes to sharing data with multiple clients, a Client-Server model has been used in the earlier days. This model has been used every day for different applications. Different functions will be carried out by the server and client during the exchange of data with the provision of inter-process communication (Oluwatosin, 2014). The scalability issues in point-to-point model have been addresses with the help of the Client Server Model. A special server will serve the requests of all the clients in the network. It is also called “many-to-one” architecture (RTI, 2015).

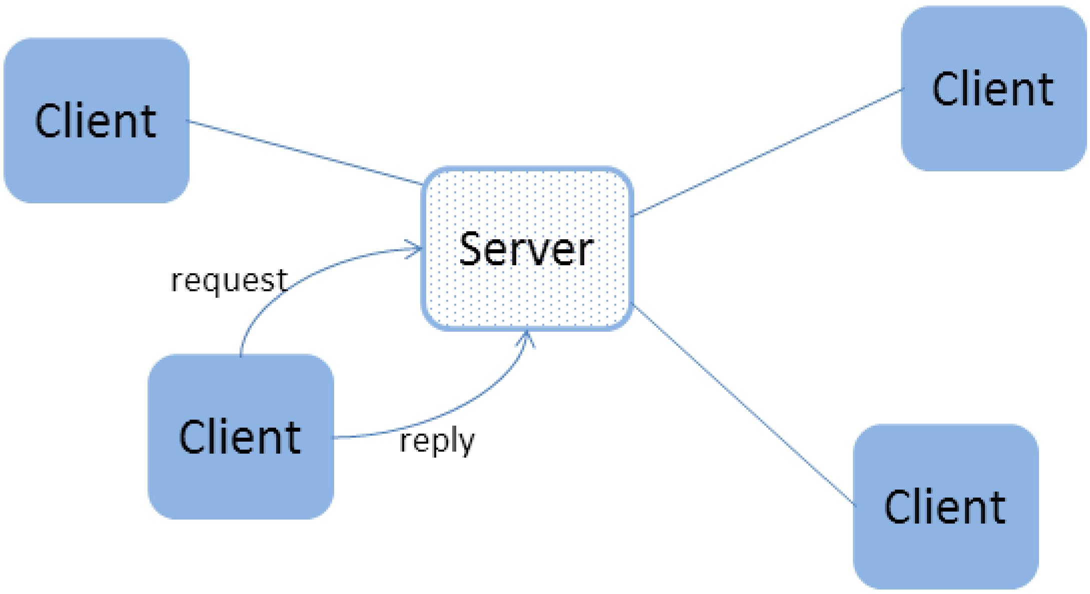


Figure 2-Client-server is many-to-one communications (RTI, 2015)

Several drawbacks have been identified in this model which are Security, Interoperability, reusability, and performance. The security aspect raised concern with the model (Sawsan Ali Hamid, 2020). The client server model reveals the actual source and destination addresses to any adversaries during data transmission (Duchessi and Chengalur-Smith, 1998). Due to this, several attacks have been happened.

A peer-to-peer model has been used to overcome the drawbacks of Client Server Model. Any computer can act as a server or a client depending on what is most appropriate to the system at the time (Loo, 2003). There is no central coordination by servers and every node communicates with the other nodes in the network and they mostly exchange files (S Venu Gopal, 2016). The security in Peer-to-Peer Model satisfies the Confidentiality, Integrity, and Availability (CIA) triage (Stefan Kraxberger, 2009). The cost for implementing the Peer-to-Peer model is less compared to Client Server Model. Some other advantages of Peer-to-Peer model are Reliability, Scalability, and sharing of resources among all the nodes equally (Roomi, 2020, November 15).

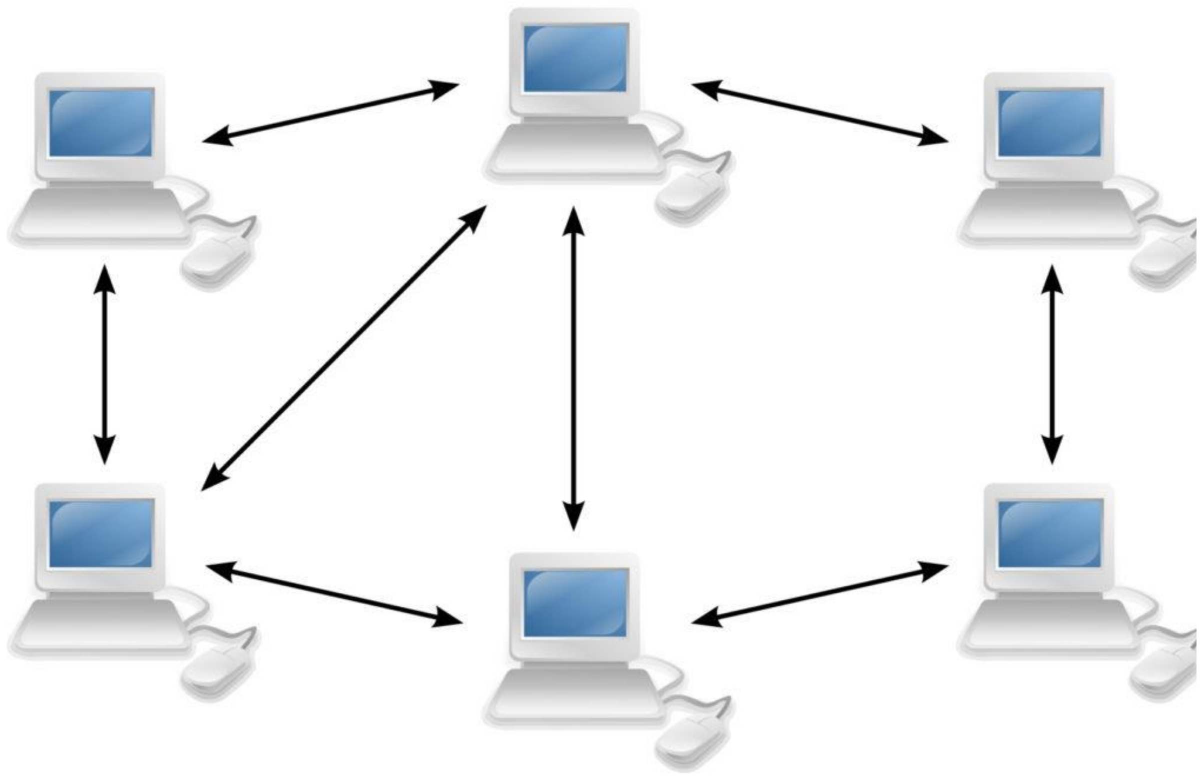


Figure 3-Peer-to-Peer Networks (CyberAgents, 2017)

IPFS (Inter-Planetary File System) protocol has been used for implementing the Peer-to-Peer model. It is a decentralized system based on a peer-to-peer protocol. It stores each file with a unique fingerprint called a cryptographic hash according to the content of the file (Huang et al., 2020). All the nodes are interconnected in the network and the data will be exchanged between the nodes. Adversaries cannot find the details about data from which source to which destination the data has been transferred.

IPFS stores and retrieves IPFS objects for Pee-to-Peer system. IPFS object is a data structure with two fields:

Field Name	Description
Data	It is an unstructured binary data blob with size <256 KB.
Links	These are array of Link structures. These are the links to other IPFS objects.

Table 1-IPFS Object data structure

Each Link Structure has three data fields:

Field Name	Description
Name	The name of the Link.
Hash	It is the hash of the linked IPFS object.

Size	It is the size of the linked IPFS object, and it consists of the size of the links following this.

Table 2-IPFS Object Link Structure (Infura, 2021)

Multicast DNS (MDNS) is used to establish communication between the nodes in the IPFS network (IPFS, 2021a). Whenever the communication gets started, the first communication happens between the nodes in the IPFS network is the exchange of MDNS information. This will setup the connections between the nodes and makes IPFS ready for exchanging files/data. The figure 1 in Appendix Section shows the MDNS between nodes.

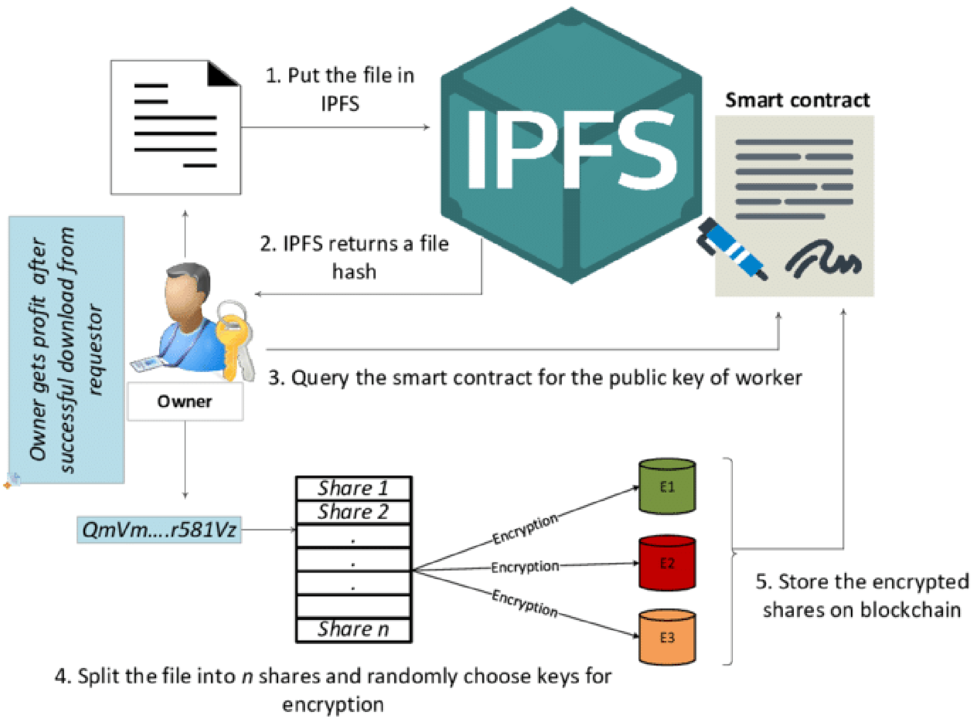


Figure 4-Data sharing on IPFS by owner (Javaid, 2019)

Another protocol which was also taken into consideration is the Whisper protocol. Whisper is a peer-2-peer decentralized messaging protocol used to maintain secrecy (Technologies, 2021). Whisper works on the off-chain part of DApps which means that there is no correlation between whisper and blockchain. In Whisper protocol, the information is stored in a payload which is then encrypted by applying the padding (Zhang et al., 2021). This protocol is used to achieve darkness which is a way of anonymity maintained between the nodes. This means the information about sender or receiver cannot be attained through packet analysis. The communication happens only on the basis of hashes of the recipients and 100% obfuscated communication is maintained (Tomu, 2018).

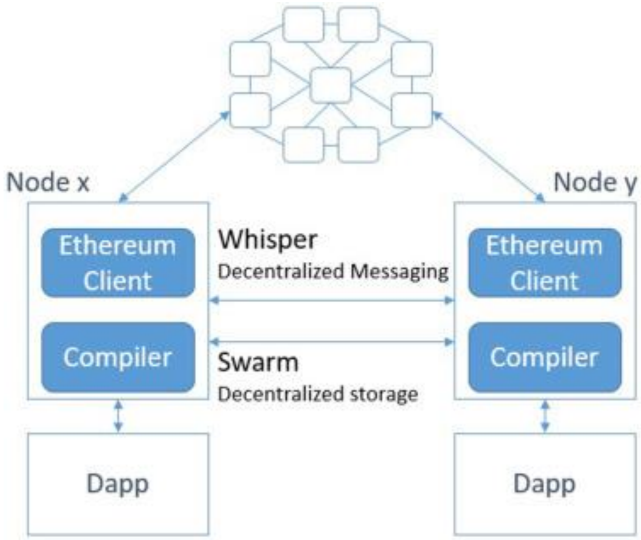


Figure 5-Whisper Protocol (Joanna Moubaraka, 2020)

Whisper nodes send and receive envelopes which are the packets. The envelop consists of encrypted payload and some metadata in plain format, because this data will be used for decryption. The envelop has the following format:

Header	Description
Version	Upto 4 bytes. It indicates encryption method. If Version is higher than current, envelope could not be decrypted, and therefore only forwarded to the peers.
Expiry time	4 bytes (UNIX time in seconds)
TTL	4 bytes (time-to-live in seconds)
Topic	4 bytes of arbitrary data
AESNonce	12 bytes of random data (only present in case of symmetric encryption)
Data	Byte array of arbitrary size (contains encrypted message).
EnvNonce	8 bytes of arbitrary data (used for PoW calculation).

Table 3-Whisper Envelop Format (Ethereum, 2019)

Whisper nodes know nothing about content of envelopes which they cannot decrypt. The nodes pass envelopes around regardless of their ability to decrypt the message, or their interest in it at all. This is an important component in Whisper's dark communications strategy.

Ipfs has been chosen as the protocol than Whisper protocol for this experiment to implement the Peer-to-Peer network and to transfer data.

Features	IPFS Protocol	Whisper Protocol
Usage	It is used to Used to transfer files from one node to the other nodes	It is a Messaging protocol which sends exchanges messages between the nodes
Node Security	Source and destination addresses are not visible (i.e., anonymization will be maintained)	Whisper maintains darkness for nodes (darkness helps in maintaining anonymization)
Data Security	Data is encrypted during transmission	Messages are encrypted during transmission
Address	Node is identified based on the ip address along with the type of protocol	Node is identified based on ip address
Protocol	It can be operated using two protocols: Libp2p IPFS	It can be operated using one protocol: Whisper

Table 4-Comparison of IPFS Protocol with Whisper Protocol

Existing Work

There are three fundamental principles to understanding IPFS:

1. Unique identification via content addressing
2. Content linking via directed acyclic graphs (DAGs)
3. Content discovery via distributed hash tables (DHTs)

IPFS can be setup for establishing connection with other nodes which are around the world. It has been achieved with the help of Internet. IPFS is also available as Desktop version which is called IPFS Desktop. By establishing IPFS globally, any node can send and receive files/data from other nodes which are part of the IPFS global network. This has been implemented in the existing works (IPFS, 2021b).

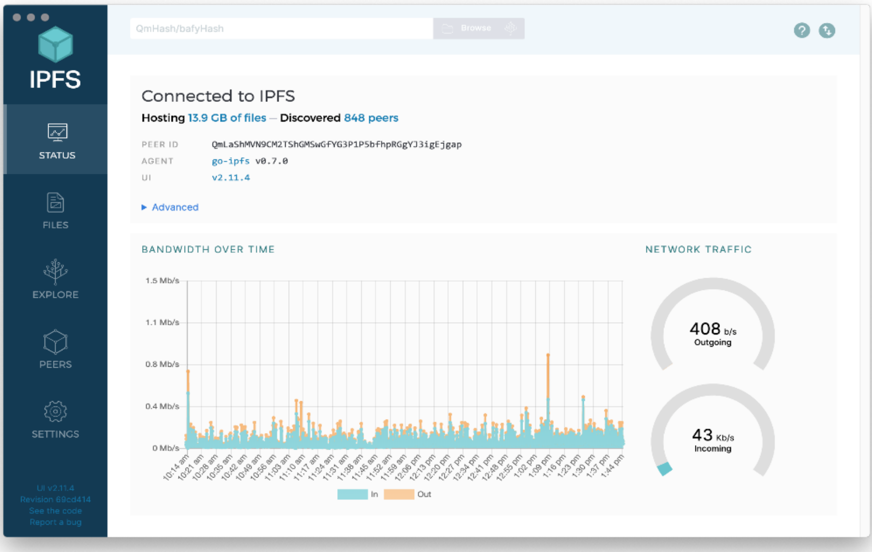


Figure 6-IPFS Desktop

In this paper, IPFS has been setup privately which is isolating the nodes in the private IPFS network from the global IPFS nodes.

Research design

Scientific Methodology has been used for this research and experiments have been conducted.

The virtualization software named “Oracle VM VirtualBox” has been used to create the virtual machines (Server and Clients) for the experiments. Along with these, the Kali Linux Virtual Machine has also been used for Wireshark to capture the traffic which is generated during data transmission and results were evaluated. The Client-Server Model (using Python Programming Language) and Peer-to-Peer Model (using GO Language) have been setup to conduct the experiments.

In addition to that, the network settings in Virtual Box for all virtual machines were set to use “Host-Only Adapter”. In this way, the traffic captured is only from these virtual machines and that gives clear results and evaluation will be quick and easy.

Along with this, the Promiscuous Mode in network settings for Kali Linux should be set to Allow All so that then Wireshark will capture all the traffic of the data transmission happened between the Server and the Clients. The Figure (1) in Appendix Section represents this setting.

Client-Server Model:

The Client-Server model is set up using python client server library. Three virtual machines are used with one of the virtual machines acting as the server. The information for the virtual machines is as of below.

Server Machine	
Name	Ubuntu ipfs Server
IP address	192.168.56.103
Client 1	
Name	Ubuntu ipfs Client – 1
IP address	192.168.56.104
Client 2	
Name	Ubuntu ipfs Client – 2
IP address	192.168.56.105

Table 5-Information of Virtual Machines

The server machine acts as the central file storage system. It stores the files and transfers file to the client when requested. The client machine requests and wait for file from the server machine.

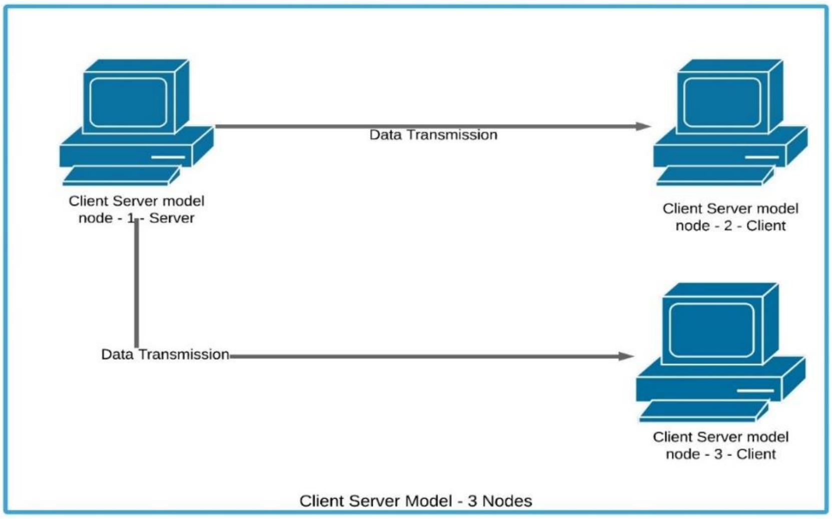


Figure 6-Client-Server Model

Roadmap:

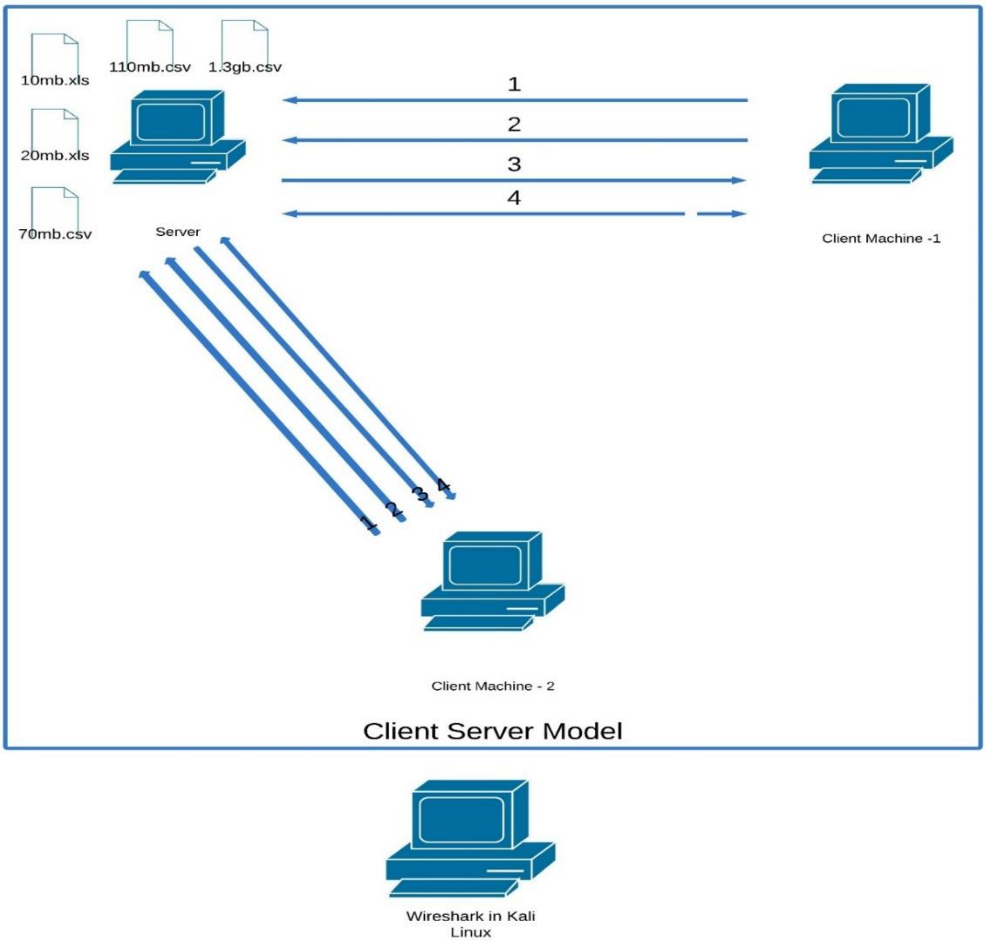


Figure 7-Roadmap of Client Server Model - 1. Client Machine 1 or 2 connects with Server Machine. 2. Client Machine 1 or 2 requests the file from server. 3. Server Transfers the file to the requested Client Machine 1 or 2. 4. The source and Destination Addresses are visible in Wireshark along with the actual data which is not encrypted.

Peer-to-Peer Model:

The Peer-to-Peer model is setup using the IPFS. The IPFS protocol is written in GO language. The setup of the experiment is like the Client-Server experiment. 3 virtual machines are used with one machine as the server and the other 2 virtual machines as the client. Figure 11 provides an overview of the model.

The following steps shows how to connect one node to the other node to establish connection between multiple nodes for IPFS Protocol:

1. By using GO language, IPFS can be installed in all the nodes. Once it is installed, the config file in .ipfs folder must be configured as shown below:

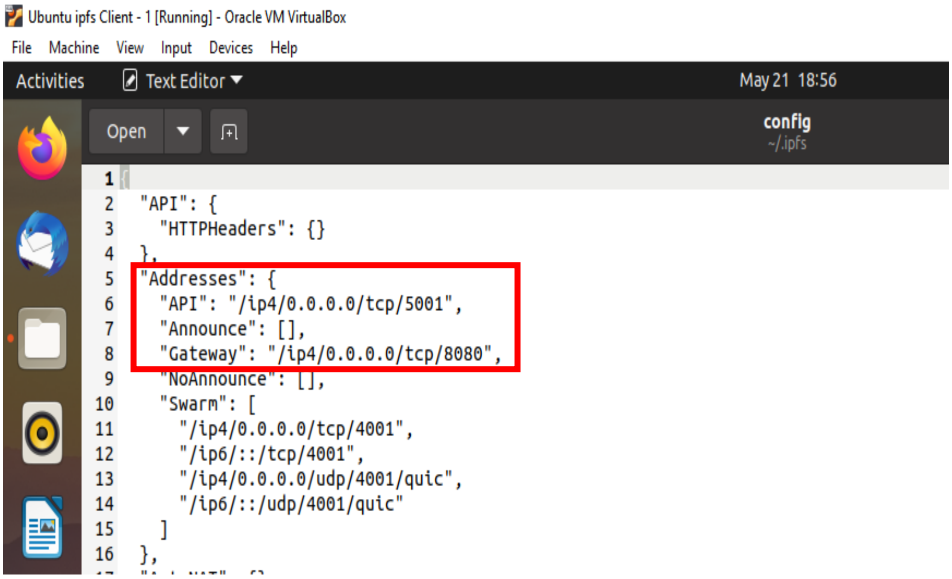


Figure 8-Configuration of config file in .ipfs folder

2. Then the swarm key is generated in Server Machine and that will be copied to other nodes which makes all nodes having the same key. The following figures show the commands for the swarm key are:
   go get -u github.com/Kubuxu/go-ipfs-swarm-key-gen/ipfs-swarm-key-gen

   ipfs-swarm-key-gen & > ~/.ipfs/swarm.key

   A swarm will be generated in the .ipfs folder and that will be copied into the other nodes. In this way, the communication will established without conflicts.

3. The following is used to remove all existing nodes in the ipfs network:
   ipfs bootstrap rm -all
4. Every node will be started with the command “ipfs daemon”. The Figure 2 in Appendix section represents the function in Server machine.
5. The command “ipfs id” shows all the details about the node. It shows the id of the node which is used to connect with other nodes. The Figures (3) (4) (5) in Appendix

Section shows the details for all the nodes in the ipfs network which will be connected next.

6. Each machine has a unique id which is used to join nodes. The command “ipfs bootstrap add” is used to add the ipfs nodes to one another to form the private IPFS network. The figure (6) in Appendix Section represents the function in Server Machine (eleks, 2021) (Tutorials, 2018).

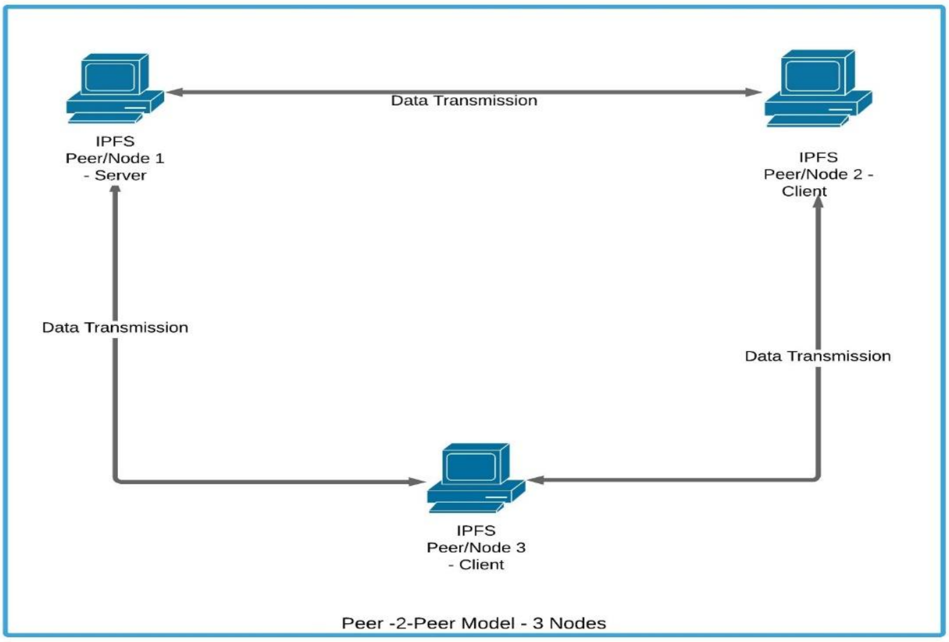


Figure 9-Peer-to-Peer Model using IPFS Protocol

Roadmap:

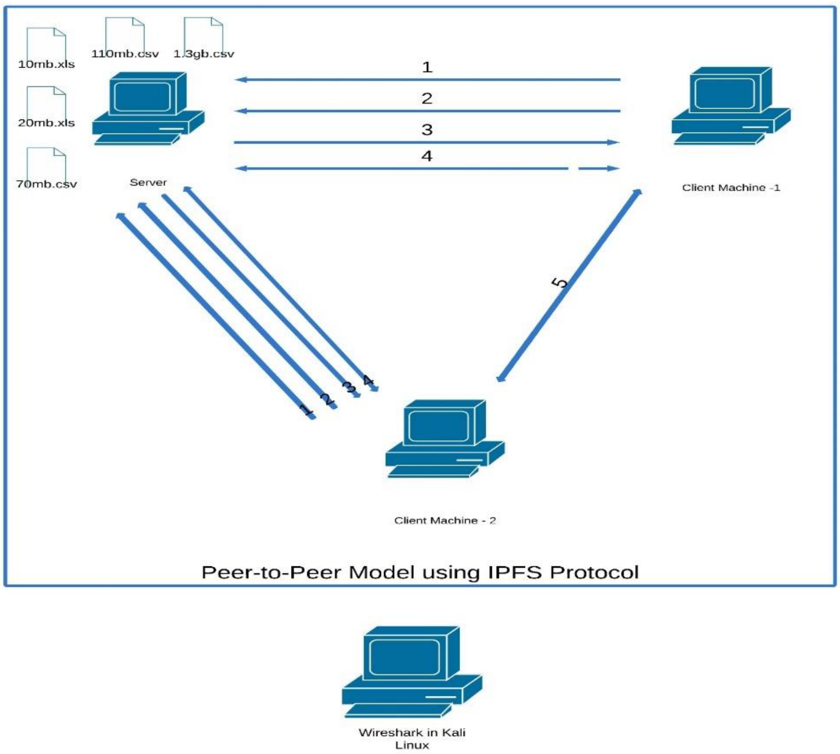
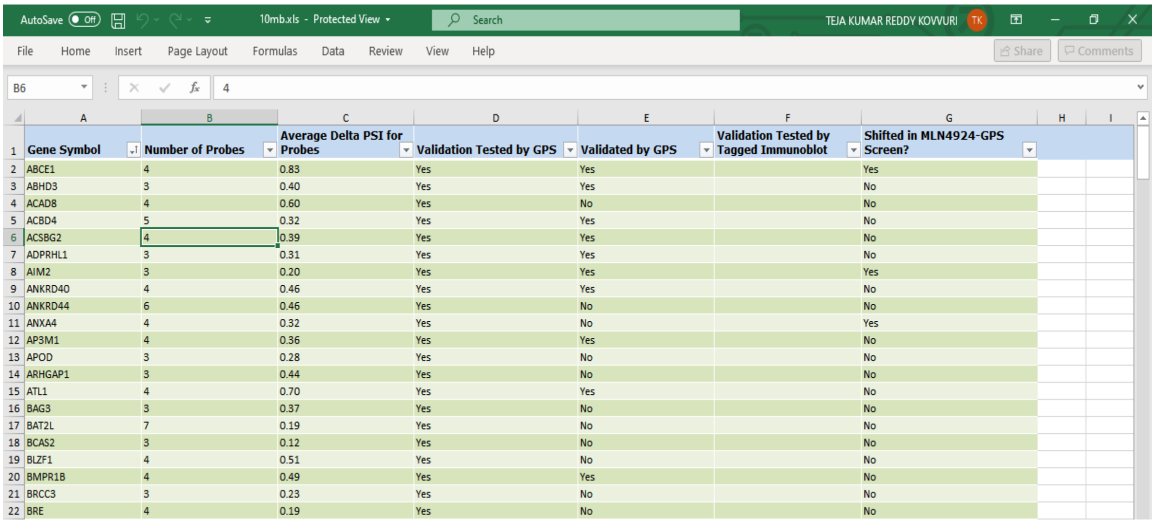


Figure 10-Peer-to-Peer Model using IPFS Protocol Roadmap - 1) Client Machine connects with Server Machine. 2) Client Machine requests the file from server. 3) Server Sends the Requested file (encrypted). The Server Broadcasts the data to all Nodes in the network. 4) Source and Destination addresses are not identifiable in Wireshark as all nodes participate in data transfer. 5) Clients Communicate with each other.

Artefact Development:

The purpose of the experiment is to evaluate the weakness in the existing client-server model and overcoming that with the help of a Peer – to – Peer model protocol named IPFS. By using this protocol, the nodes in a Peer – to – Peer network does not provide the actual data and the destination to where the data is getting transferred. This helps in maintaining the anonymity during the and prevents the recon phase of the Advanced Persistent Threats.

Experiments are conducted on the Client-Server model and the Peer-to-Peer model. The files which were chosen for this experiment are 5 excel files for easy recognition and understanding of data during analysis in Wireshark. The data in the files consist of columns and rows which represent data belonging to a particular entity in each row. 10mb.xls. Excel files maintain a lot of data which is easy to track and find during the data transfer. This is because each data is organized in the form of columns and rows and searching to find a particular word is very easy. As data is transferred in the form of small bits which are equivalent to the words, it will be easy to recognise them and find the same in the excel files.



	A	B	C	D	E	F	G
1	Gene Symbol	Number of Probes	Average Delta PSI for Probes	Validation Tested by GPS	Validated by GPS	Validation Tested by Tagged Immunoblot	Shifted in MLN4924-GPS Screen?
2	ABCE1	4	0.83	Yes	Yes		Yes
3	ABHD3	3	0.40	Yes	Yes		No
4	ACAD8	4	0.60	Yes	No		No
5	ACBD4	5	0.32	Yes	Yes		No
6	ACSBG2	4	0.39	Yes	Yes		No
7	ADPRHL1	3	0.31	Yes	Yes		No
8	AIM2	3	0.20	Yes	Yes		Yes
9	ANKRD40	4	0.46	Yes	Yes		No
10	ANKRD44	6	0.46	Yes	No		No
11	ANXA4	4	0.32	Yes	No		Yes
12	AP3M1	4	0.36	Yes	Yes		No
13	APOD	3	0.28	Yes	No		No
14	ARHGAP1	3	0.44	Yes	No		No
15	ATL1	4	0.70	Yes	Yes		No
16	BAG3	3	0.37	Yes	No		No
17	BAT2L	7	0.19	Yes	No		No
18	BCAS2	3	0.12	Yes	No		No
19	BLZF1	4	0.51	Yes	No		No
20	BMPR1B	4	0.49	Yes	Yes		No
21	BRCC3	3	0.23	Yes	No		No
22	BRE	4	0.19	Yes	No		No

Figure 11-10mb.xls

The Appendix Section has the remaining figures for 20mb.xls, 70mb.csv, 110mb.csv, and 1.3gb.csv files.

Experiment on Client - Server model

The server starts and listens for connections from clients. Once the clients get connected, the file transfer between the nodes take place as per the request of the client. The server accepts connection from each client at a time and finishes the transmission of data before accepting connection from another client.

Wireshark is used to consolidate the traffic and the results will be analysed. Further experiments are evaluated. The Figure-5 representing Wireshark in Kali Linux can be seen in Appendix section.

The Procedure for the experiment

1. Server is configured to start and listen for client to establish a connection. When the connection with the client is established, the server sends the requested file to the client.

```
ktkr@ktkr-VirtualBox:~/Desktop/tcp-filetransfer$ python3 server_tcp.py
Server listening...
```

Figure 12-Python Client Server model - Server machine

2. Client is started and waiting to establish connection with server. In the Client Machine, the server IP address and the port number are supplied. In addition to that, the method to request the file which is the GET method will also be supplied. Finally, the client gives the file name.

```
ktkr@ktkr-VirtualBox:~/Desktop/tcp-filetransfer$ python3 client_tcp.py
Enter server IP: 192.168.56.103
Enter port number: 7005
Connected to server.
Enter a GET or SEND command:GET

Enter name of file: 10mb.xls
Receiving file..
Done receiving file
Connected to server.
Enter a GET or SEND command:
```

Figure 13-Python Client Server model - Client Machine-1

The server searches for the requested file. Once the file is found, the file will be sent by the server. The following figure shows that the file has been successfully sent by the server to the client. The client receives the file. If in case the server does not find the file, it displays no such file or directory available message.

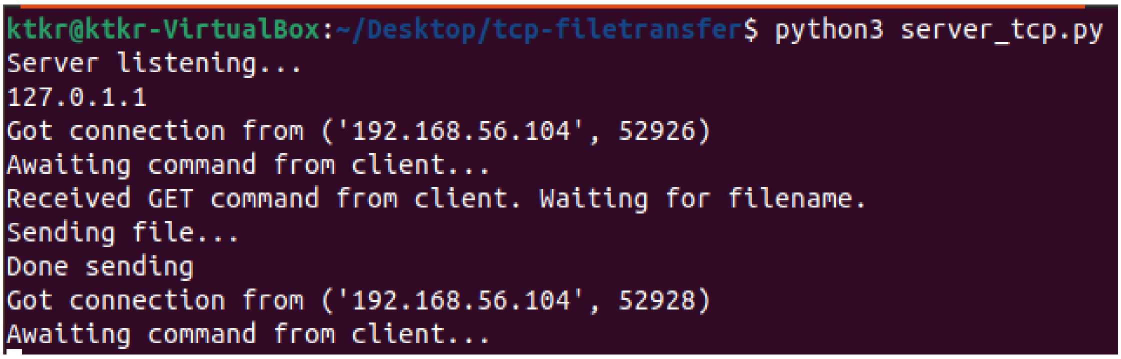


Figure 14-Server Machine sending data

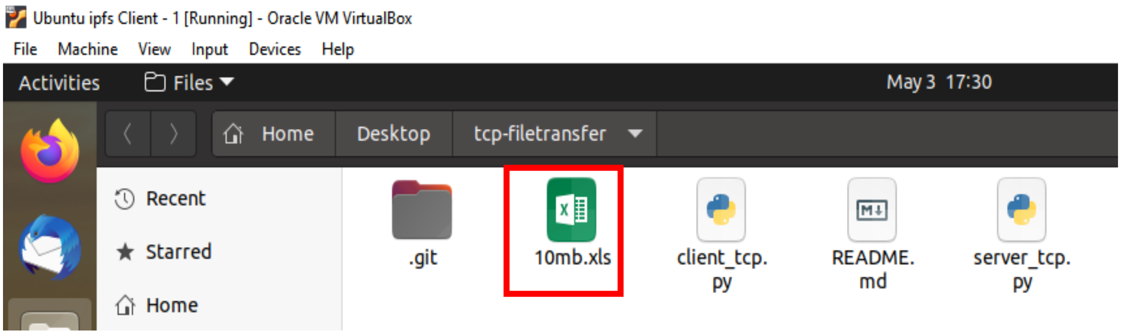
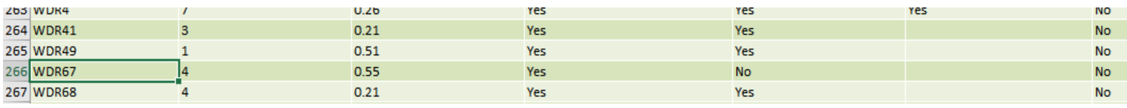


Figure 15-Transferred file visible in Client Machine-1

Result

The excel files used in the experiment are transferred from the server to the client. There is a total of 5 excel files used. A certain key word is selected from the 5 excel files as identity for the excel file. Figure 8 shows the key word “WDR67” is used. The key words for the other excel files are revealed in figures (8) (10) (12) (14) in the appendix section.



263	WDR4	7	0.26	Yes	Yes	Yes	No
264	WDR41	3	0.21	Yes	Yes		No
265	WDR49	1	0.51	Yes	Yes		No
266	WDR67	4	0.55	Yes	No		No
267	WDR68	4	0.21	Yes	Yes		No

Figure 16-“WDR67” in 10mb.xls is selected

The traffic between server and client has been captured in Wireshark. The payload in the traffic reveals the actual keyword selected in the selected excel files. In client-server model, the concept relies on encryption tool such as SSL or TLS to hide the content of the traffic. These results are shown in figure 9. The result for other excel files are available in Figure (7) (9) (11) (13) in appendix.

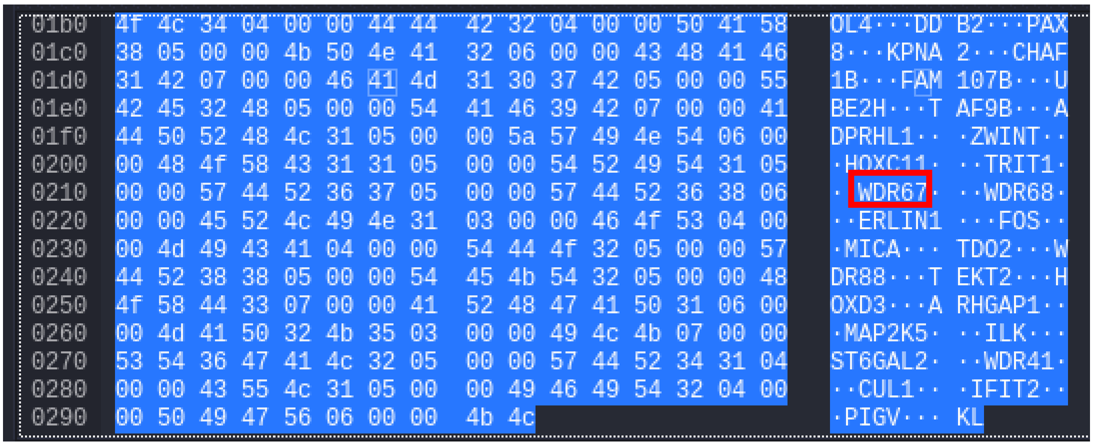


Figure 17-Actual data visibility in Wireshark

The table below provides additional information of the experiment for the client-server model.

File	Client Name	Destination address	Data visibility	Sample data	Data identification in traffic
10mb.xls	Ubuntu ipfs Client – 1	192.168.56.104	Yes	WDR67	Yes
20mb.xls	Ubuntu ipfs Client – 2	192.168.56.105	Yes	149.29	Yes
1.3gb.csv	Ubuntu ipfs Client – 1	192.168.56.104	Yes	evie.hamby@gmail.com	Yes
110mb.csv	Ubuntu ipfs Client – 2	192.168.56.105	Yes	44005	Yes
70mb.csv	Ubuntu ipfs Client – 1	192.168.56.104	Yes	Global Rank, Tld Rank	Yes

Table 6-Result and information for the Client-Server model experiment.

This experiment shows that there is no security, and anyone can see the plain text using tools like Wireshark. An adversary can know to which node/address the data has been passed. This leads to more several attacks by adversary on the communication.

Experiment on Peer – to - Peer model

The same experiments have been conducted on the same nodes using IPFS protocol. In this experiment, the traffic will be analyzed to see any actual data or to identify the destination to where the data is transferred.

The Procedure for the experiment

In the server, IPFS stores the files in its database and generates a unique hash value for the file. The "add" command is used to add file into the database. It is used to upload the 5 excel files into the database. Figure 12 shows how the command is used for the uploading of the excel file.

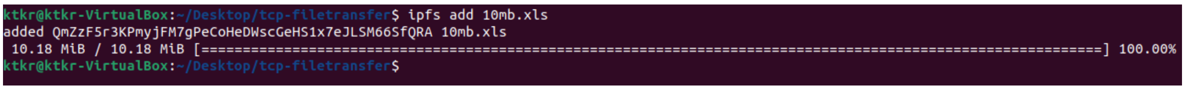


Figure 18-Peer-to-Peer Model Server Machine using IPFS Protocol

In Client, the "get" command is used to send a request to the ipfs server/node for the file. The example of the command used to request for the file can be seen in figure 14.

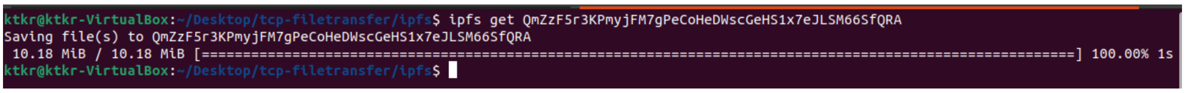


Figure 19-Peer-to-Peer Model Client Machine-1 using IPFS Protocol

Result

With the help of Wireshark, the entire data transmission has been captured and analyzed.

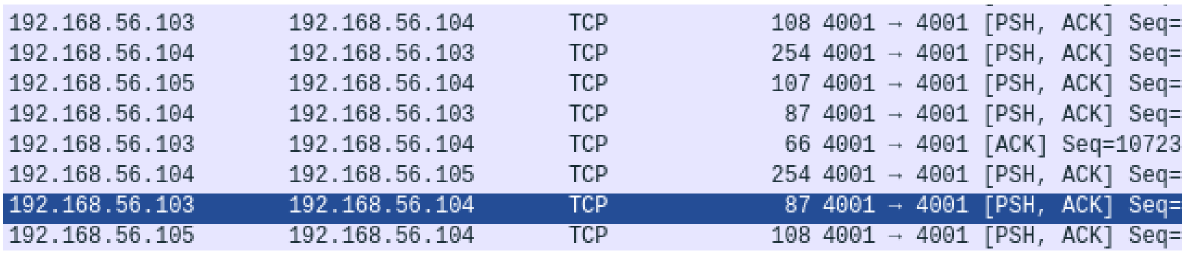


Figure 20-Analysis of Traffic using Wireshark in Kali Linux

In IPFS, the sender uses the broadcasting method to communicate with other node. The actual data is transferred to all nodes and the legitimate node will receive the data. Other node rejects the data. This helps in maintaining the anonymity. It makes tracking of traffic difficult as this is demonstrated in figure 15. The source and destination are unknown.

IPFS encrypts the data before it is being transmitted to the other nodes. The diagram in figure 16 shows the content is not readable. This helps to prevent the content in the payload of the traffic to be exposed in the process of man in the middle attack. Hence, this enhances the security of transmission and keep the network safe from adversary.

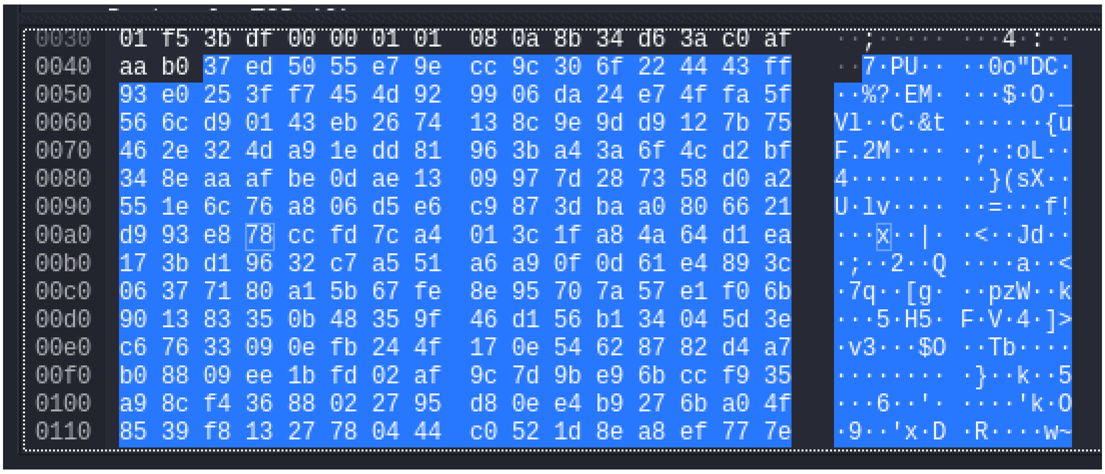


Figure 21-Data Analysis in Wireshark - Data is Encrypted

The experiment is repeated for the 5 excel files and the results are noted in table 2. In table 2, the size of the file does not affect the result of the network.

Sample	Client	Destination address	Data visibility	Sample data	Original data identification in traffic
10mb.xls	Ubuntu ipfs Client – 1	Unknown	NO	WDR67	NO
20mb.xls	Ubuntu ipfs Client – 2	Unknown	NO	149.29	NO
1.3gb.csv	Ubuntu ipfs Client – 2	Unknown	NO	evie.hamby@gmail.com	NO
110mb.csv	Ubuntu ipfs Client – 2	Unknown	NO	44005	NO
70mb.csv	Ubuntu ipfs Client – 1	Unknown	NO	Global Rank, Tld Rank	NO

Table 7-Result and information for the Peer-to-Peer model experiment.

Evaluation

Summary Table for comparison of Client-Server model and Peer-to-Peer model:

Type of Model	Sample	Client	Destination Address	Data visibility	Sample Data	Original data identification in traffic
Client Server Model	10mb.xls	Ubuntu ipfs Client – 1	192.168.56.104	Yes	WDR67	Yes
	20mb.xls	Ubuntu ipfs Client – 2	192.168.56.105	Yes	149.29	Yes
	1.3gb.csv	Ubuntu ipfs Client – 2	192.168.56.104	Yes	evie.hamby@gmail.com	Yes
	110mb.csv	Ubuntu ipfs Client – 2	192.168.56.105	Yes	44005	Yes
	70mb.csv	Ubuntu ipfs Client – 1	192.168.56.104	Yes	Global Rank, Tld Rank	Yes
Peer-to-Peer Model	10mb.xls	Ubuntu ipfs Client – 1	Unknown	NO	WDR67	NO

	20mb.xls	Ubuntu ipfs Client – 2	Unknown	NO	149.29	NO
	1.3gb.csv	Ubuntu ipfs Client – 2	Unknown	NO	evie.hamby@gmail.com	NO
	110mb.csv	Ubuntu ipfs Client – 2	Unknown	NO	44005	NO
	70mb.csv	Ubuntu ipfs Client – 1	Unknown	NO	Global Rank, Tld Rank	NO

Table 8-Comparison of the results of Client-Server Model and Peer-to-Peer Model

When the server machine using IPFS Protocol in Peer-to-Peer Model sends a file to all nodes, all the nodes receive the same data in encrypted form. The data also varies from node to node. The server sends data which is encrypted differently for each node.

Future Work

With the help of the above experiments, it is evident that the source and destination addresses are autonomous with the use of IPFS protocol which protects the nodes from adversaries. Further experiments can be conducted to find more features which are helpful for Peer-to-Peer model and strengthens the security for the nodes.

References

ALSHAMRANI, A., MYNENI, S., CHOWDHARY, A. & HUANG, D. 2019. A Survey on Advanced Persistent Threats: Techniques, Solutions, Challenges, and Research Opportunities. *IEEE Communications Surveys & Tutorials,* 21**,** 1851-1877.

BRAHIM ID MESSAOUD, K. G., MOHAMED WAHBI, MOHAMED SADIK 2016. <Advanced Persistent Threat - new analysis.pdf>.

CYBERAGENTS. 2017. *Peer-to-Peer Networks* [Online]. Available: https://www.cyberagentsinc.com/2018/09/14/peer-to-peer-networks/ [Accessed 18 May 2021].

DEV BHATNAGAR, S. S., SUNIL KUMAR KHATRI 2019. <Advance Persistant Threat and Cyber Spying - The Big Picture,.pdf>.

DUCHESSI, P. & CHENGALUR-SMITH, I. 1998. Client/server benefits, problems, best practices. *Communications of the ACM,* 41**,** 87-94.

ELEKS. 2021. *IPFS Tutorial: Building a Private IPFS Network with IPFS-Cluster for Data Replication* [Online]. Available: https://labs.eleks.com/2019/03/ipfs-network-data-replication.html [Accessed 21 May 2021].

ETHEREUM, G. 2019. *Overview | Go Ethereum* [Online]. Available: https://geth.ethereum.org/docs/whisper/whisper-overview#:~:text=Whisper%20is%20a%20pure%20identity,the%20underlying%20%C3%90%CE%9EVp2p%20Wire%20Protocol. [Accessed 30 May 2021].

HUANG, H.-S., CHANG, T.-S. & WU, J.-Y. 2020. A Secure File Sharing System Based on IPFS and Blockchain. *Proceedings of the 2020 2nd International Electronics Communication Conference.*

INFURA. 2021. *An Introduction to IPFS (Interplanetary File System) | Infura Blog | Tutorials, Case Studies, News, Feature Announcements* [Online]. Available: https://blog.infura.io/an-introduction-to-ipfs/#:~:text=At%20its%20core%2C%20IPFS%20is,%2C%20TOR%2C%20and%20even%20Bluetooth. [Accessed 22 May 2021].

IPFS. 2021a. *Configure a node | IPFS Docs* [Online]. Available: https://docs.ipfs.io/how-to/configure-node/#discovery [Accessed 22 May 2021].

IPFS. 2021b. *How IPFS works | IPFS Docs* [Online]. Available: https://docs.ipfs.io/concepts/how-ipfs-works/#content-addressing [Accessed 30 May 2021].

JAVAID, N. 2019. *Data sharing on IPFS by owner* [Online]. Available: https://www.researchgate.net/figure/Data-sharing-on-IPFS-by-owner_fig1_335652136 [Accessed 18 May 2021].

JOANNA MOUBARAKA, M. C., ERIC FILIOL 2020. *On distributed ledgers security and illegal uses*.

LOO, A. W. 2003. The future of peer-to-peer computing. *Communications of the ACM,* 46**,** 56-61.

MARTIN USSATH, D. J., FENG CHENG, CHRISTOPH MEINEL 2016. <Advanced Persistent Threats -Behind the Scenes.pdf>.

OLUWATOSIN, H. S. 2014. <Client-Server Model.pdf>.

ROOMI, M. 2020, November 15. *7 Advantages and Disadvantages of Peer to Peer Network | Drawbacks & Benefits of Peer to Peer Network* [Online]. Available: https://www.hitechwhizz.com/2020/11/7-advantages-and-disadvantages-drawbacks-benefits-of-p2p-network.html [Accessed 29 March 2021].

RTI. 2015. *Network Communications Models* [Online]. Available: https://community.rti.com/static/documentation/connext-dds/5.2.0/doc/manuals/connext_dds/html_files/RTI_ConnextDDS_CoreLibraries_GettingStarted/Content/UsersManual/Network_Communications_Models.htm [Accessed 18 May 2021].

S VENU GOPAL, N. S. R., S K LOKESH NAIK 2016. <Dynamic Sharing of Files from Disconnected Nodes.pdf>.

SAWSAN ALI HAMID, R. A. A., DR.RUAA ALI KHAMEES 2020. <What is Client-Server System_ Architecture, Issues and Challenge.pdf>.

STEFAN KRAXBERGER, U. P. 2009. <Security Concept for Peer-to-Peer Systems.pdf>.

SUN, T. N., TEODOROV, C. & ROUX, L. L. 2020. Operational design for advanced persistent threats. *Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings.*

TEAM, I. 2019. *Advanced Persistent Threat: Challenge Accepted* [Online]. Available: https://blog.teamascend.com/advanced-persistent-threat [Accessed 18 May 2021].

TECHNOLOGIES, E. 2021. *Decentralized Application Messaging with Whisper — Part 1* [Online]. Available: https://blog.enuma.io/update/2018/08/08/decentralized-application-messaging-with-whisper.html [Accessed 30 May 2021].

TOMU, D. 2018. *Whisper — Shh!. What if we could send an encrypted… | by David Tomu | Caelum Labs | Medium* [Online]. Available: https://medium.com/caelumlabs/whisper-shh-bc5416ec0046 [Accessed 30 May 2021].

IPFS Tutorials #4 - How to setup P2P Private Network IPFS, 2018. Directed by TUTORIALS, D.

ZHANG, L., ZHANG, Z., JIN, Z., SU, Y. & WANG, Z. 2020. An approach of covert communication based on the Ethereum whisper protocol in blockchain. *International Journal of Intelligent Systems,* 36**,** 962-996.

ZHANG, L., ZHANG, Z., JIN, Z., SU, Y. & WANG, Z. 2021. An approach of covert communication based on the Ethereum whisper protocol in blockchain. *International Journal of Intelligent Systems,* 36**,** 962-996.

Appendix

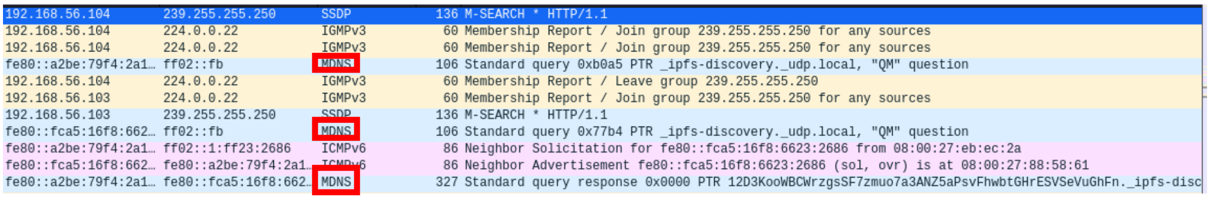


Figure 1-MDNS in IPFS Protocol connection establishment

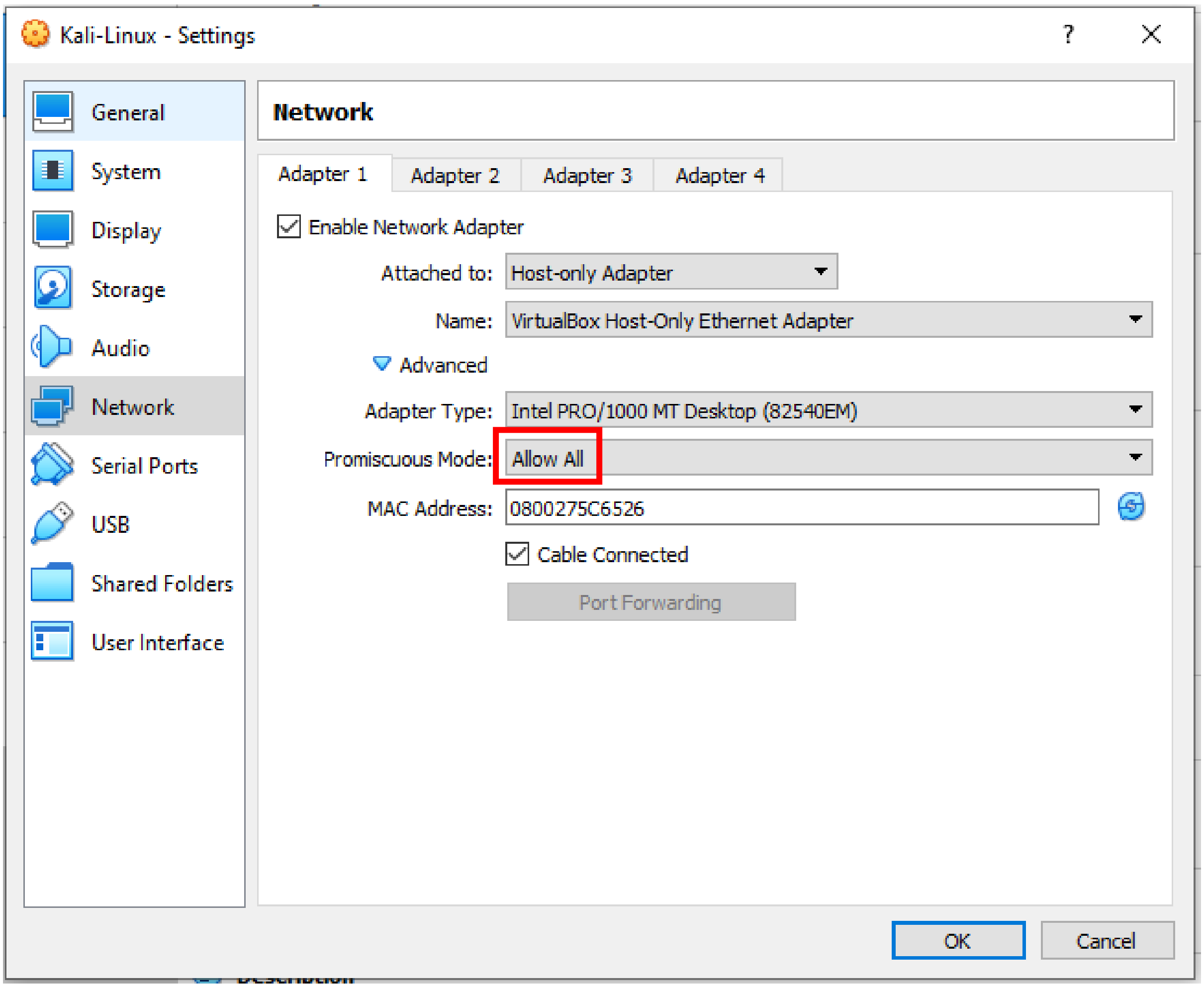


Figure 2-Promiscuous Mode-Allow All in Network Settings of Virtual Box for Kali Linux Virtual Machine

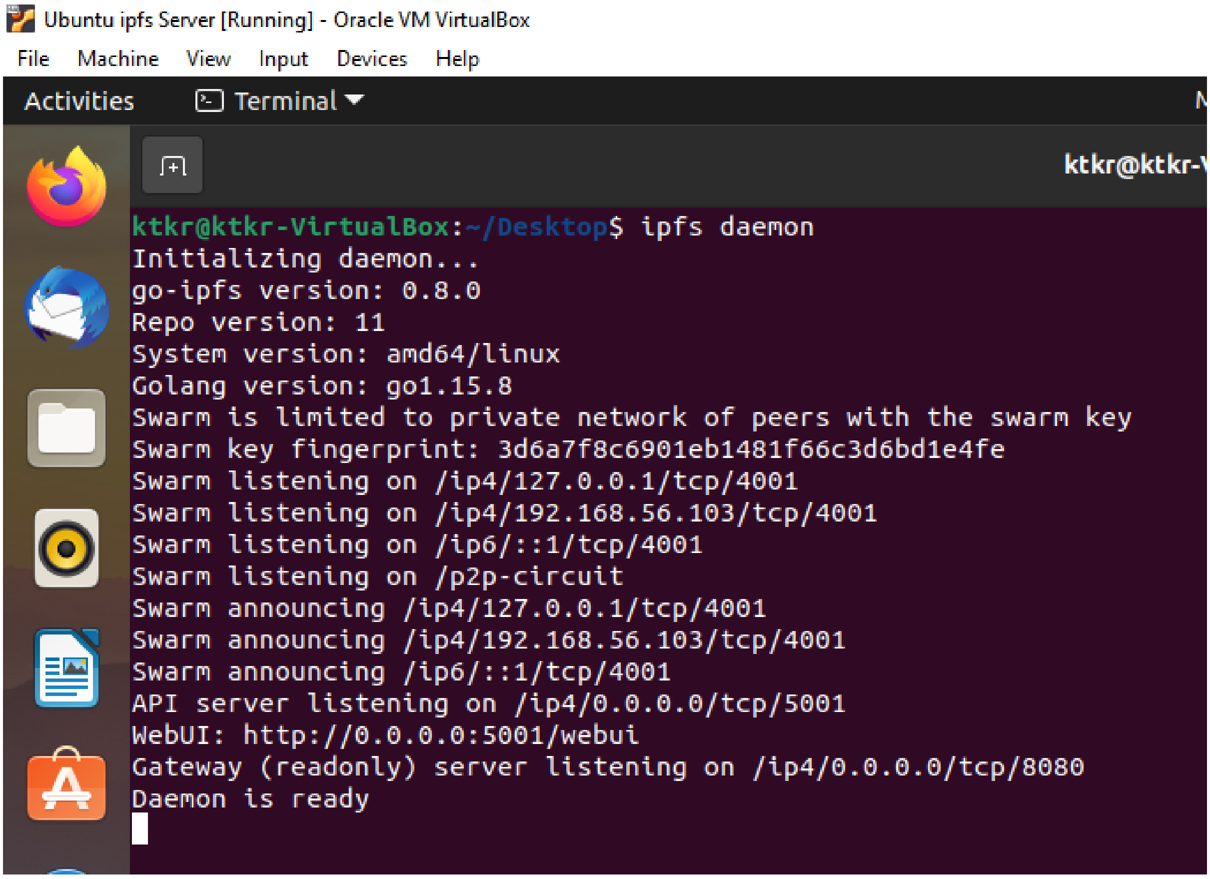


Figure 3-ipfs daemon in Server Machine

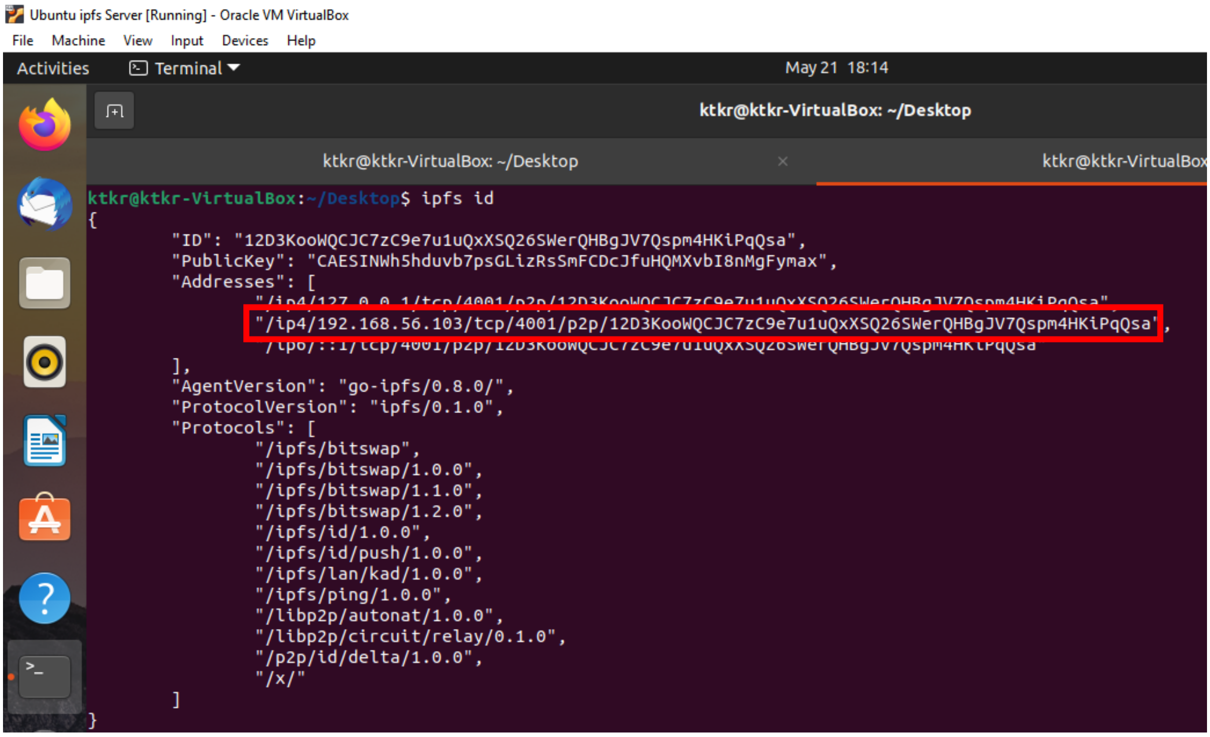


Figure 4-ipfs details for Server Machine

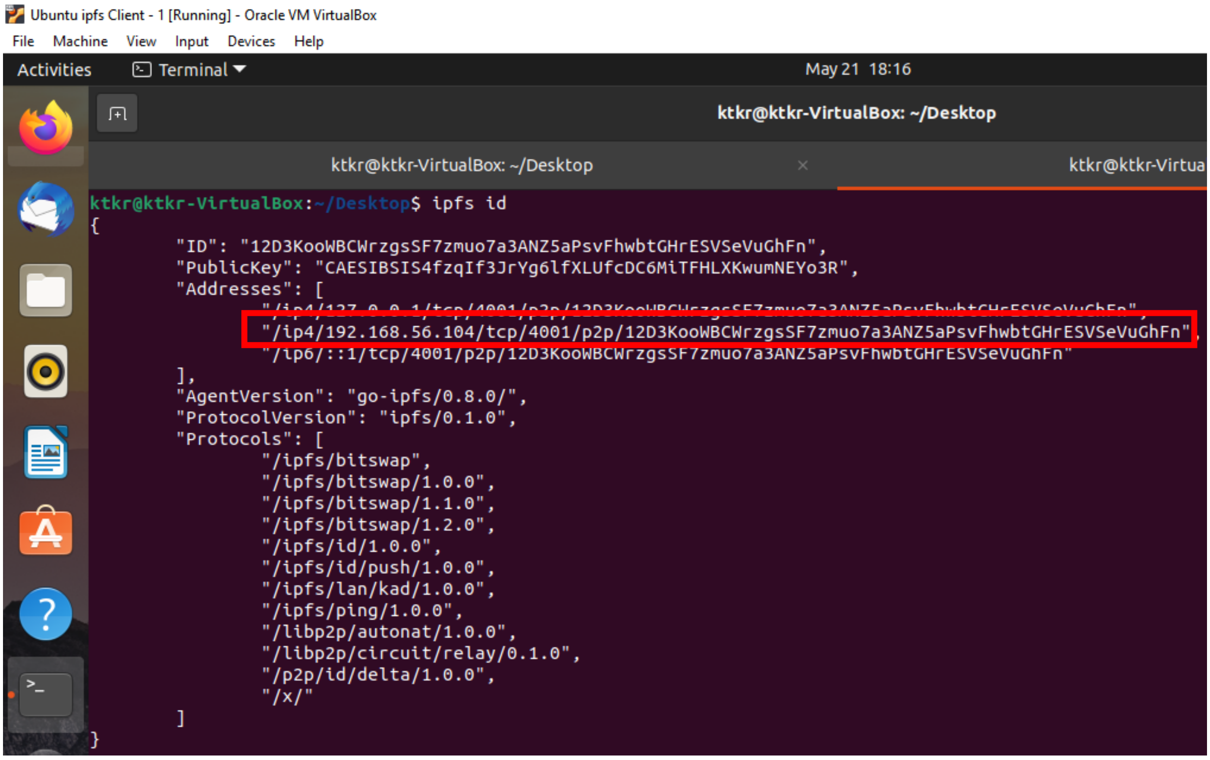


Figure 5-ipfs details for Ubuntu ipfs Client -1

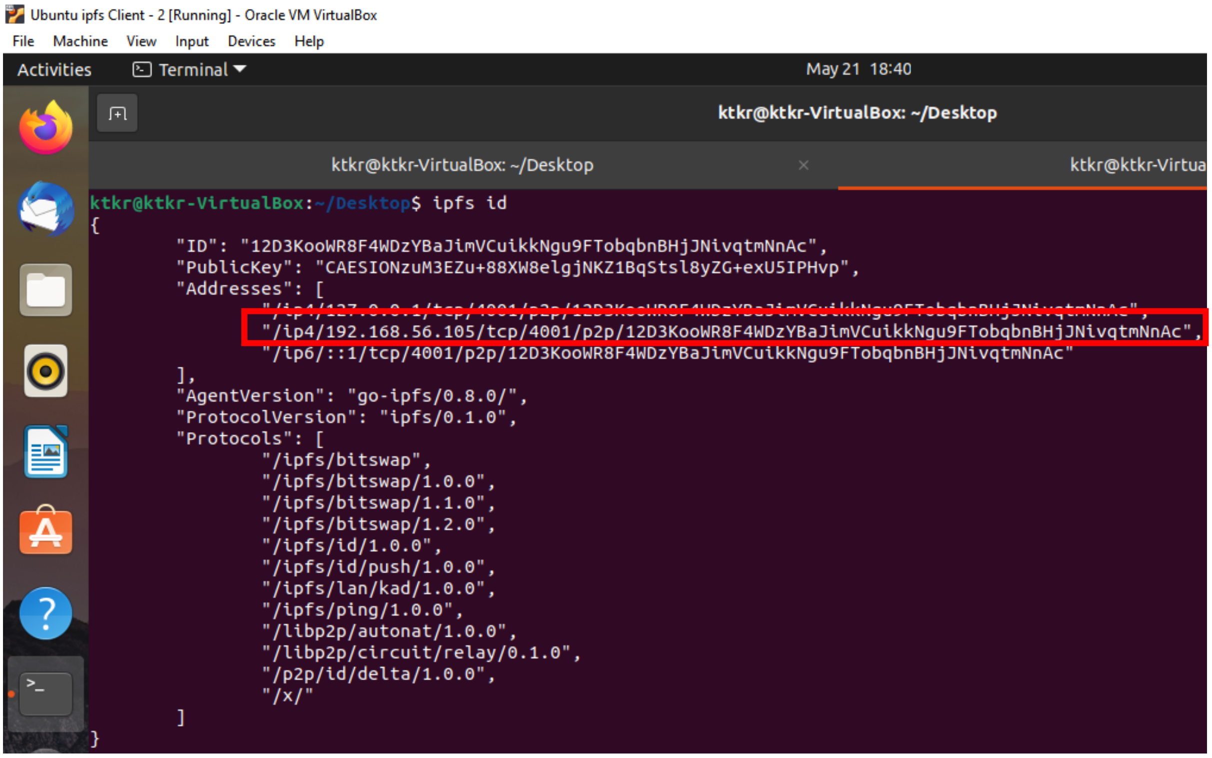
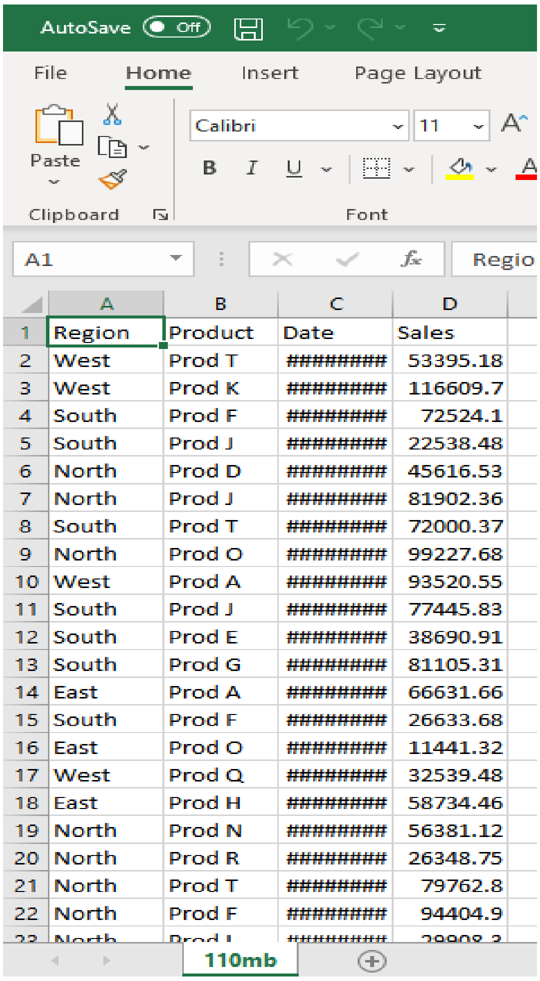


Figure 6-ipfs details of Ubuntu ipfs Client – 2



	A	B	C	D
1	Region	Product	Date	Sales
2	West	Prod T	#########	53395.18
3	West	Prod K	#########	116609.7
4	South	Prod F	#########	72524.1
5	South	Prod J	#########	22538.48
6	North	Prod D	#########	45616.53
7	North	Prod J	#########	81902.36
8	South	Prod T	#########	72000.37
9	North	Prod O	#########	99227.68
10	West	Prod A	#########	93520.55
11	South	Prod J	#########	77445.83
12	South	Prod E	#########	38690.91
13	South	Prod G	#########	81105.31
14	East	Prod A	#########	66631.66
15	South	Prod F	#########	26633.68
16	East	Prod O	#########	11441.32
17	West	Prod Q	#########	32539.48
18	East	Prod H	#########	58734.46
19	North	Prod N	#########	56381.12
20	North	Prod R	#########	26348.75
21	North	Prod T	#########	79762.8
22	North	Prod F	#########	94404.9

Figure 7-20mb.xls

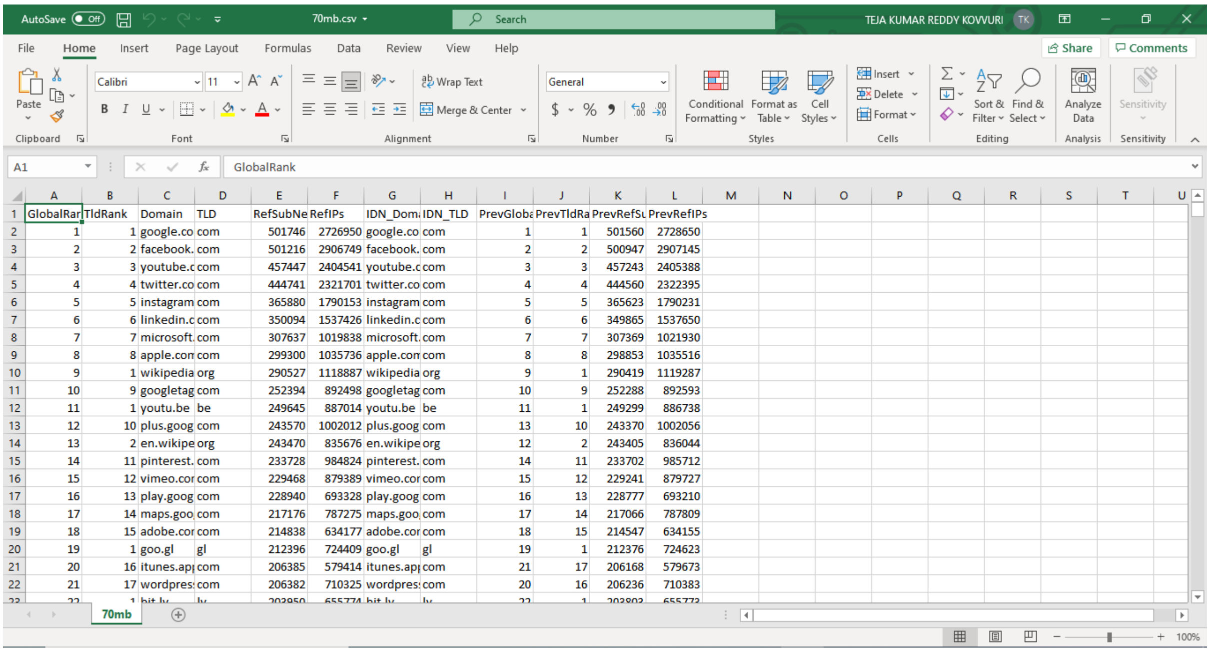


Figure 8-70mb.csv

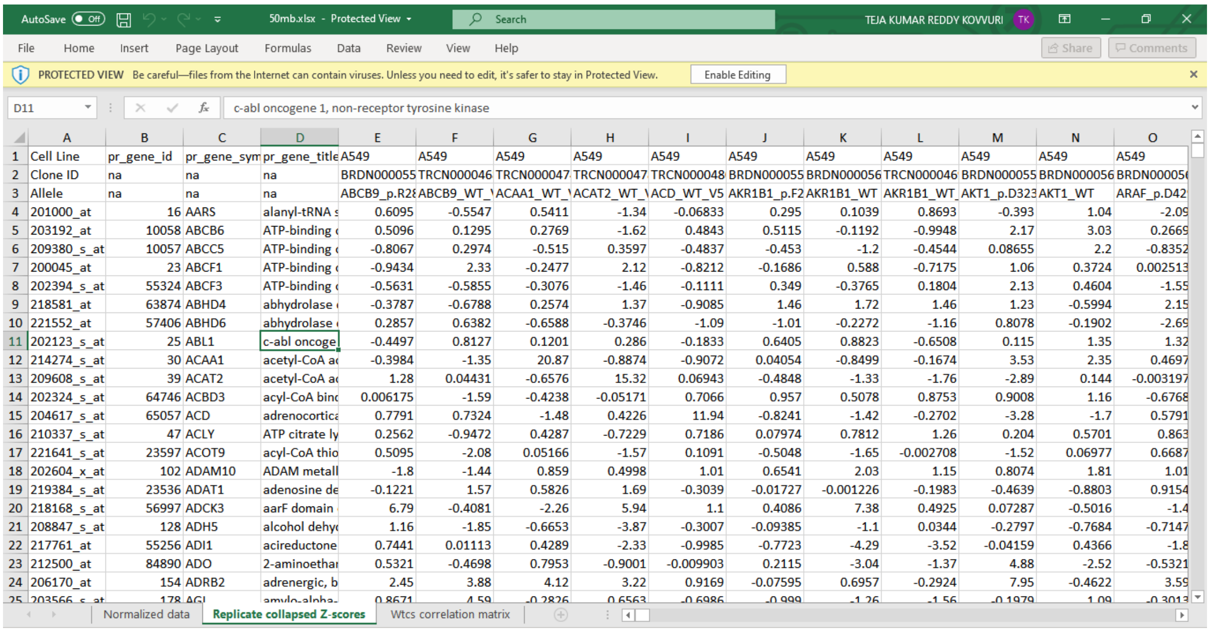


Figure 9-110mb.csv

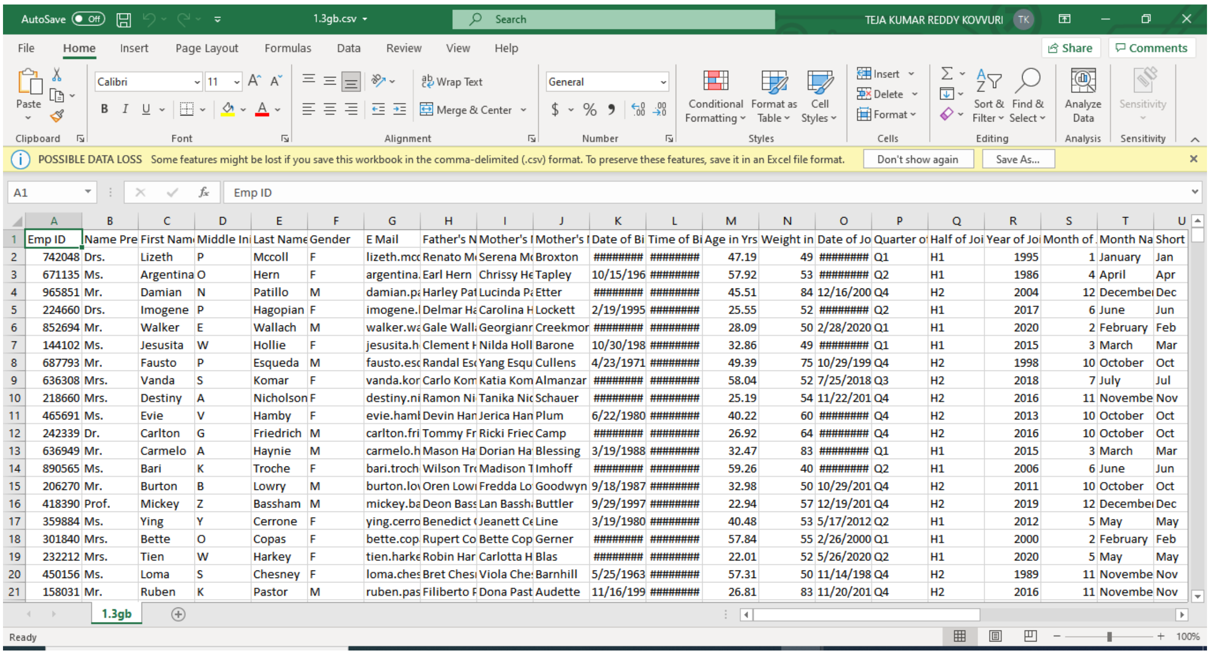


Figure 10-1.3gb.csv

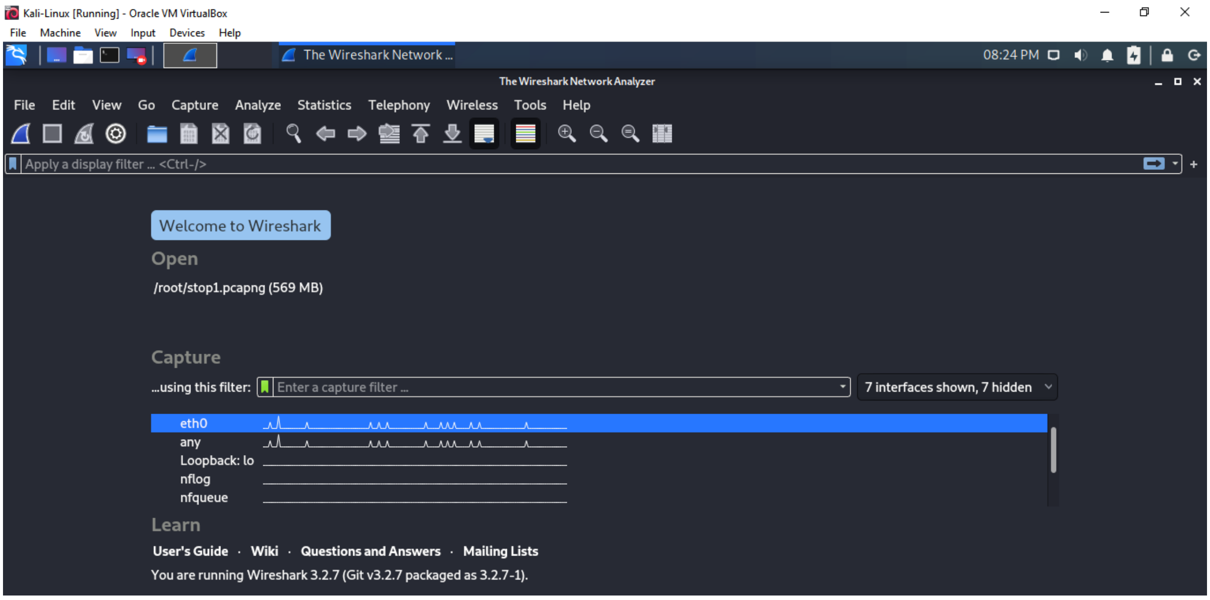
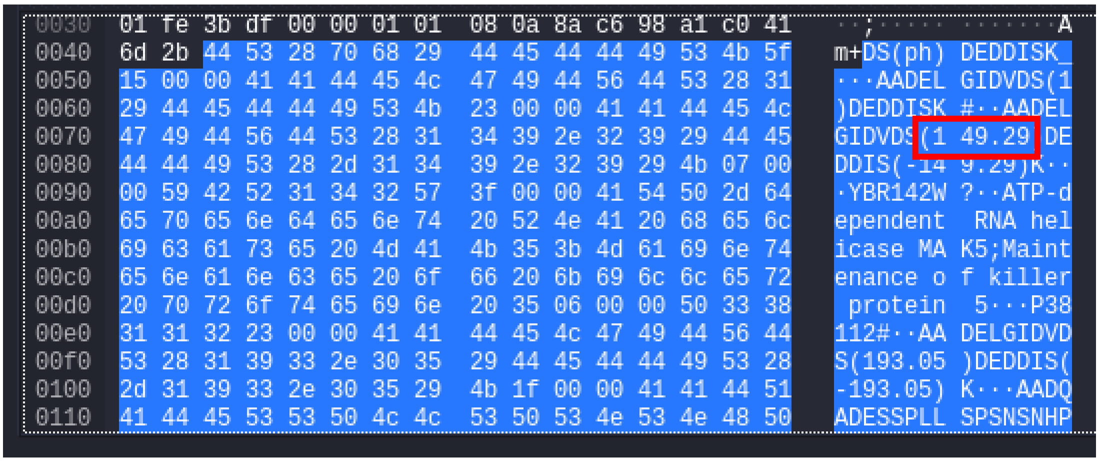
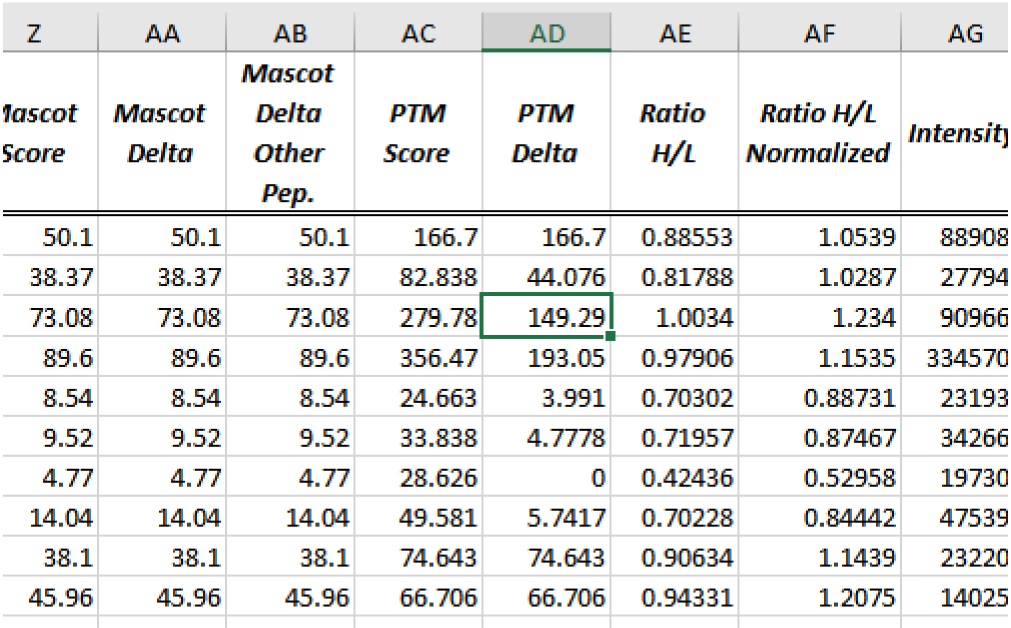


Figure 11-Wireshark in Kali Linux



```
0030  01 fe 3b df 00 00 01 01  08 0a 8a c6 98 a1 c0 41   ··;····· ·······A
0040  6d 2b 44 53 28 70 68 29  44 45 44 44 49 53 4b 5f   m+DS(ph) DEDDISK_
0050  15 00 00 41 41 44 45 4c  47 49 44 56 44 53 28 31   ···AADEL GIDVDS(1
0060  29 44 45 44 44 49 53 4b  23 00 00 41 41 44 45 4c   )DEDDISK #··AADEL
0070  47 49 44 56 44 53 28 31  34 39 2e 32 39 29 44 45   GIDVDS(1 49.29)DE
0080  44 44 49 53 28 2d 31 34  39 2e 32 39 29 4b 07 00   DDIS(-14 9.29)K··
0090  00 59 42 52 31 34 32 57  3f 00 00 41 54 50 2d 64   ·YBR142W ?··ATP-d
00a0  65 70 65 6e 64 65 6e 74  20 52 4e 41 20 68 65 6c   ependent  RNA hel
00b0  69 63 61 73 65 20 4d 41  4b 35 3b 4d 61 69 6e 74   icase MA K5;Maint
00c0  65 6e 61 6e 63 65 20 6f  66 20 6b 69 6c 6c 65 72   enance o f killer
00d0  20 70 72 6f 74 65 69 6e  20 35 06 00 00 50 33 38    protein  5···P38
00e0  31 31 32 23 00 00 41 41  44 45 4c 47 49 44 56 44   112#··AA DELGIDVD
00f0  53 28 31 39 33 2e 30 35  29 44 45 44 44 49 53 28   S(193.05 )DEDDIS(
0100  2d 31 39 33 2e 30 35 29  4b 1f 00 00 41 41 44 51   -193.05) K···AADQ
0110  41 44 45 53 53 50 4c 4c  53 50 53 4e 53 4e 48 50   ADESSPLL SPSNSNHP
```

Figure 12-Data visibility in Wireshark



Z	AA	AB	AC	AD	AE	AF	AG
Mascot Score	*Mascot Delta*	*Mascot Delta Other Pep.*	*PTM Score*	*PTM Delta*	*Ratio H/L*	*Ratio H/L Normalized*	*Intensity*
50.1	50.1	50.1	166.7	166.7	0.88553	1.0539	88908
38.37	38.37	38.37	82.838	44.076	0.81788	1.0287	27794
73.08	73.08	73.08	279.78	149.29	1.0034	1.234	90966
89.6	89.6	89.6	356.47	193.05	0.97906	1.1535	334570
8.54	8.54	8.54	24.663	3.991	0.70302	0.88731	23193
9.52	9.52	9.52	33.838	4.7778	0.71957	0.87467	34266
4.77	4.77	4.77	28.626	0	0.42436	0.52958	19730
14.04	14.04	14.04	49.581	5.7417	0.70228	0.84442	47539
38.1	38.1	38.1	74.643	74.643	0.90634	1.1439	23220
45.96	45.96	45.96	66.706	66.706	0.94331	1.2075	14025

Figure 13-Actual data in Excel File

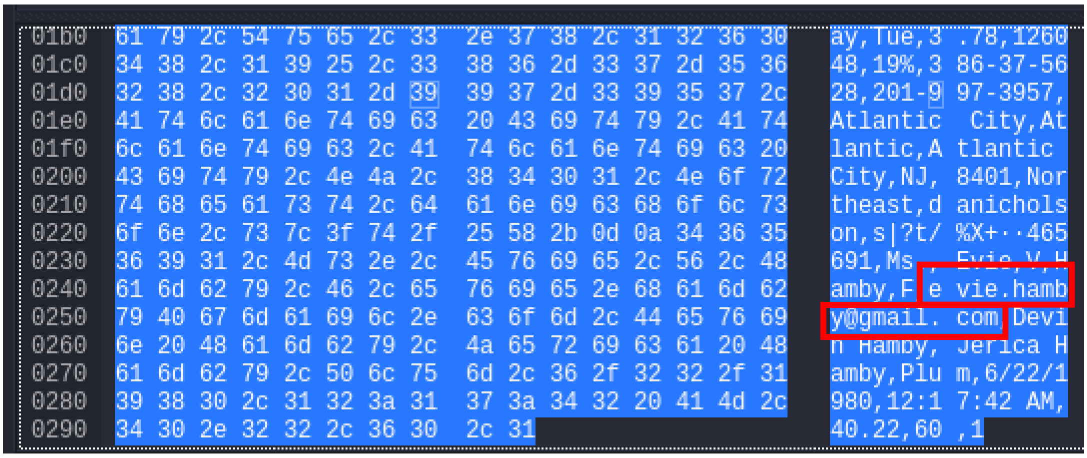


Figure 14-data identified - evie.hamby@gmail.com

9	636308	Mrs.	Vanda	S	Komar	F	vanda.komar@aol.com	Carlo Kom	Katia I
10	218660	Mrs.	Destiny	A	Nicholson	F	destiny.nicholson@gmail.com	Ramon Ni	Tanika
11	465691	Ms.	Evie	V	Hamby	F	evie.hamby@gmail.com	Devin Han	Jerica
12	242339	Dr.	Carlton	G	Friedrich	M	carlton.friedrich@gmail.com	Tommy Fr	Ricki F

Figure 15-Actual Data in Excel File - evie.hamby@gmail.com

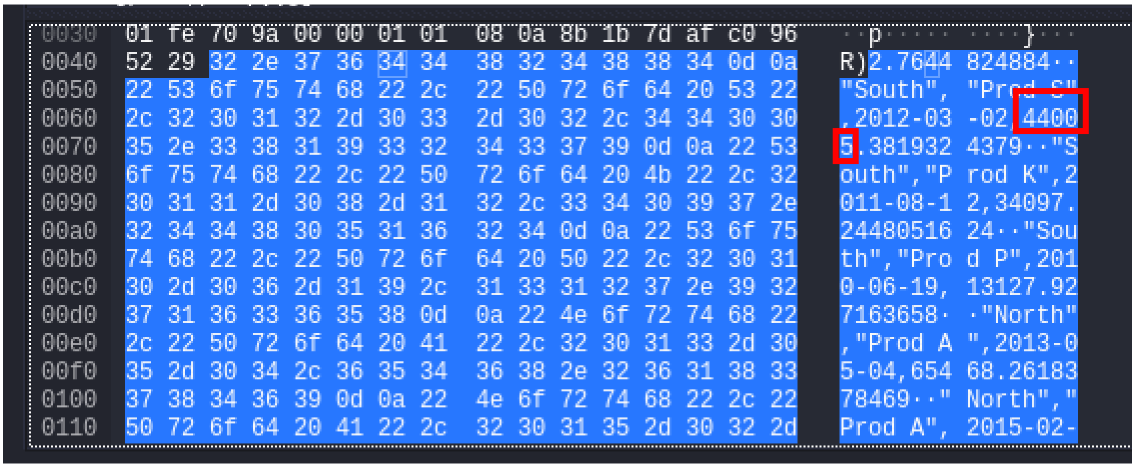


Figure 16-Data identified in Wireshark-44005

97678	South	Prod B	#########	103429.7
97679	West	Prod K	#########	5908.56
97680	North	Prod T	#########	44005.63
97681	North	Prod C	#########	63105.52

Figure 17-Actual Data in Excel FIle-44005

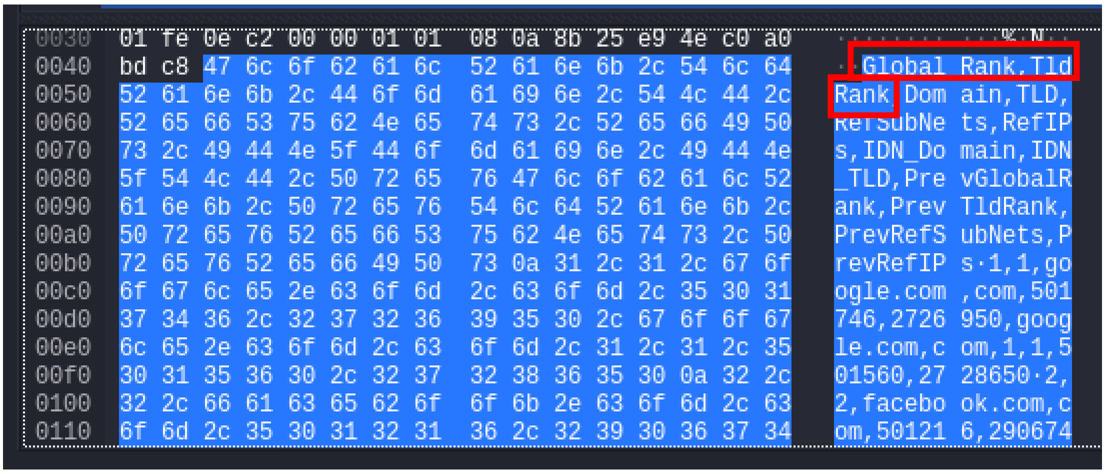


Figure 18-Data identified in Wireshark

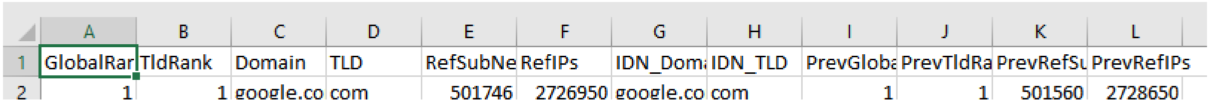


Figure 19-Actual data in Excel Data

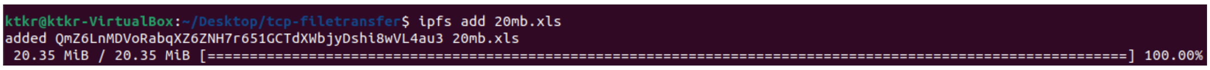


Figure 20-Peer-to-Peer Model Server Machine for 20mb.xls file

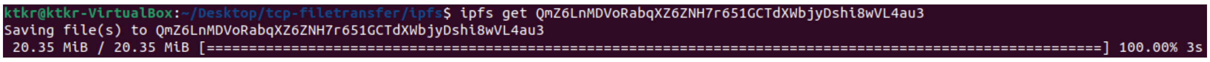


Figure 21-Peer-to-Peer Model CLient Machine -2 using IPFS Protocol

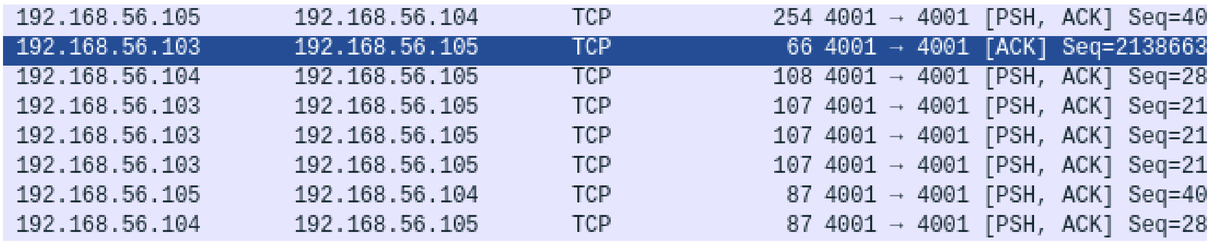


Figure 22-Traffic Analysis in Wireshark for 20mb.xls file

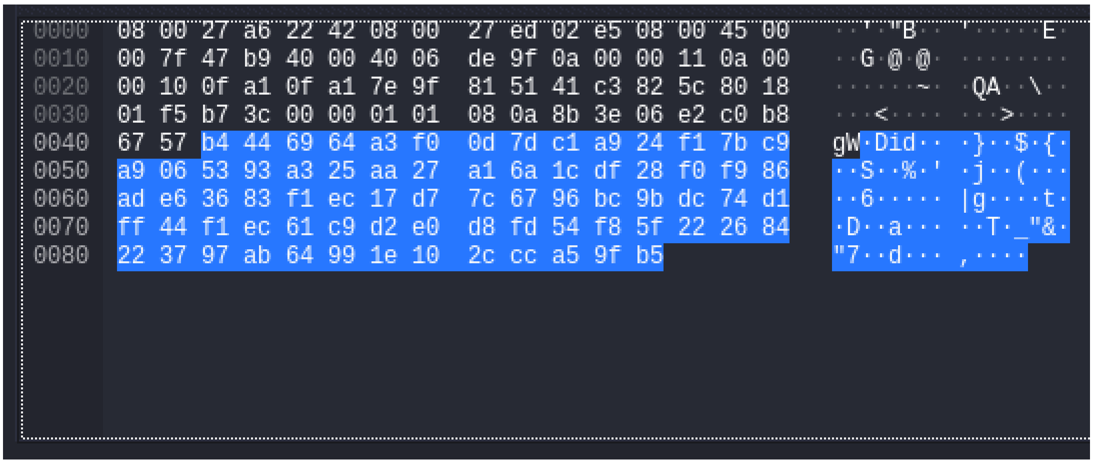


Figure 23-Encrypted data for 20mb.xls file in Wireshark

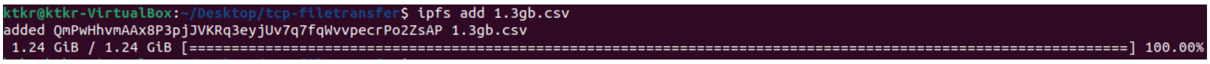


Figure 24-Peer-to-Peer Model Server Machine using IPFS Protocol for 1.3gb.csv file

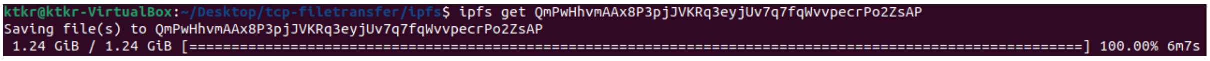
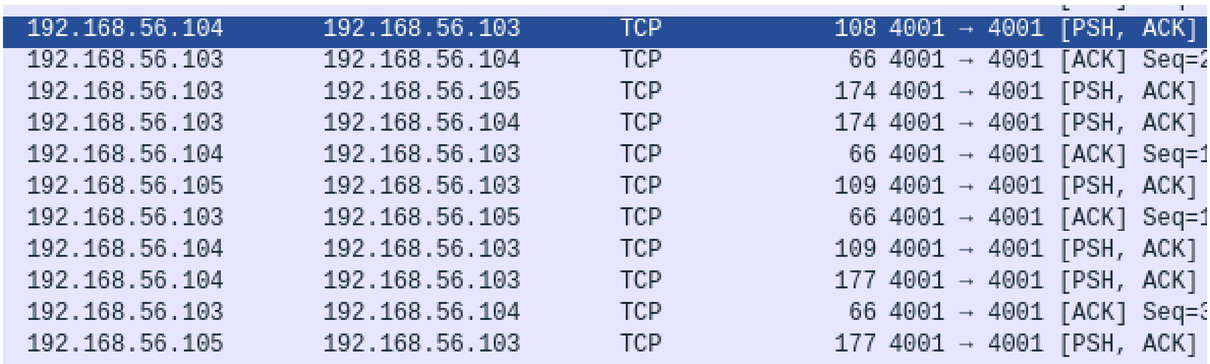


Figure 25-Peer-to-Peer Model Client Machine-1 using IPFS Protocol for 1.3gb.csv file



192.168.56.104	192.168.56.103	TCP	108	4001 → 4001 [PSH, ACK]
192.168.56.103	192.168.56.104	TCP	66	4001 → 4001 [ACK] Seq=2
192.168.56.103	192.168.56.105	TCP	174	4001 → 4001 [PSH, ACK]
192.168.56.103	192.168.56.104	TCP	174	4001 → 4001 [PSH, ACK]
192.168.56.104	192.168.56.103	TCP	66	4001 → 4001 [ACK] Seq=1
192.168.56.105	192.168.56.103	TCP	109	4001 → 4001 [PSH, ACK]
192.168.56.103	192.168.56.105	TCP	66	4001 → 4001 [ACK] Seq=1
192.168.56.104	192.168.56.103	TCP	109	4001 → 4001 [PSH, ACK]
192.168.56.104	192.168.56.103	TCP	177	4001 → 4001 [PSH, ACK]
192.168.56.103	192.168.56.104	TCP	66	4001 → 4001 [ACK] Seq=3
192.168.56.105	192.168.56.103	TCP	177	4001 → 4001 [PSH, ACK]

Figure 26-Traffic in Wireshark

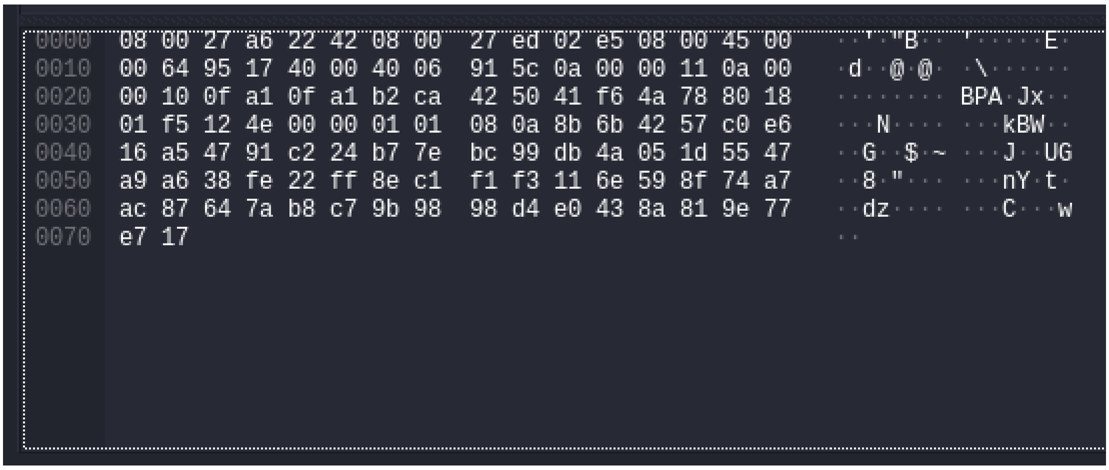


Figure 27-Encrypted Data in Wireshark

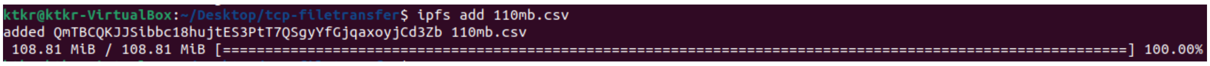


Figure 28-Peer-to-Peer Model Server Machine using IPFS Protocol for 110mb.csv file

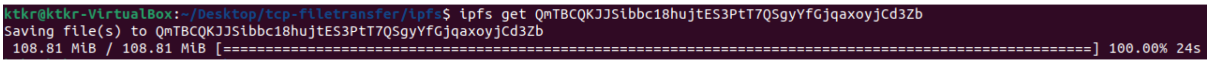


Figure 29-Peer-to-Peer Model Client Machine-2 using IPFS Protocol for 110mb.csv file

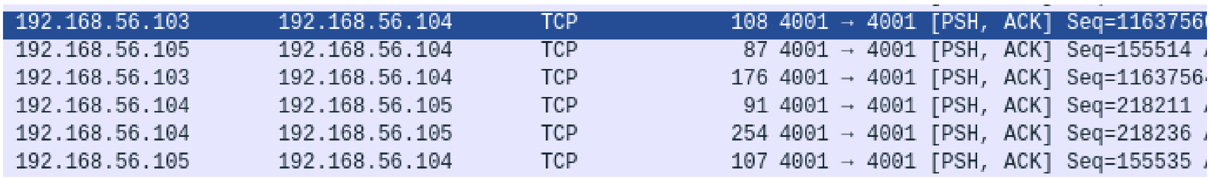


Figure 30-Traffic in Wireshark

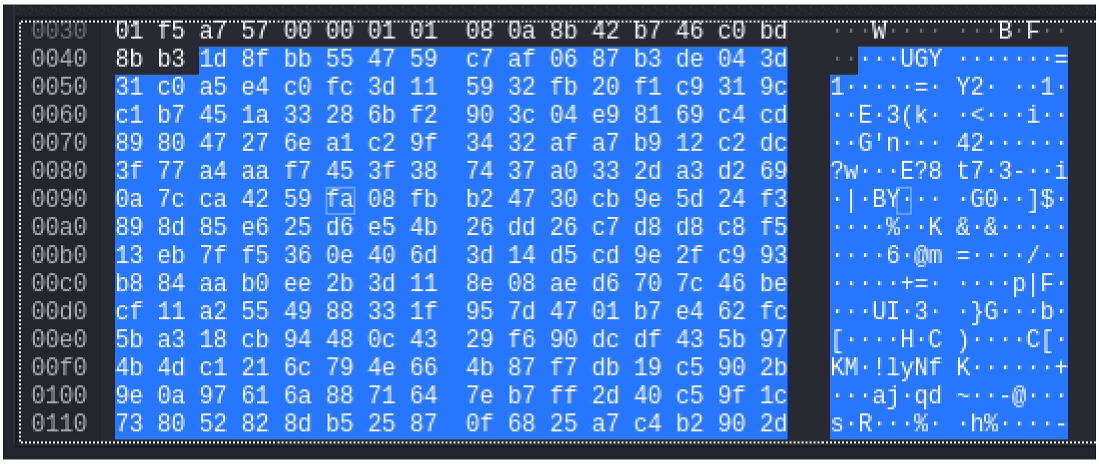


Figure 31-Encrypted Data in Wireshark

```
ktkr@ktkr-VirtualBox:~/Desktop/tcp-filetransfer$ ipfs add 70mb.csv
added QmP1fnLScFNmmDXJbcwYyDBJks2surdVZUszHWMXQXVb2U 70mb.csv
 77.33 MiB / 77.33 MiB [=====================================================================================================] 100.00%
```

Figure 32-Peer-to-Peer Model Server Machine using IPFS Protocol for 70mb.csv file

```
ubuntu@ubuntu-VirtualBox:~/Desktop/tcp-filetransfer$ ipfs get QmP1fnLScFNmmDXJbcwYyDBJks2surdVZUszHWMXQXVb2U
Saving file(s) to QmP1fnLScFNmmDXJbcwYyDBJks2surdVZUszHWMXQXVb2U
 77.35 MiB / 77.35 MiB [=====================================================================================================] 100.00% 16s
ubuntu@ubuntu-VirtualBox:~/Desktop/tcp-filetransfer$
```

Figure 33-Peer-to-Peer Model Client Machine-1 using IPFS Protocol for 70mb.csv file

192.168.56.103	192.168.56.105	TCP	107 4001 → 4001 [PSH, ACK] Seq=81399982
192.168.56.105	192.168.56.104	TCP	169 4001 → 4001 [PSH, ACK] Seq=153850 Ac
192.168.56.105	192.168.56.103	TCP	254 4001 → 4001 [PSH, ACK] Seq=287025 Ac
192.168.56.104	192.168.56.105	TCP	108 4001 → 4001 [PSH, ACK] Seq=110506 Ac
192.168.56.104	192.168.56.105	TCP	176 4001 → 4001 [PSH, ACK] Seq=110548 Ac
192.168.56.105	192.168.56.103	TCP	87 4001 → 4001 [PSH, ACK] Seq=287213 Ac
192.168.56.105	192.168.56.104	TCP	66 4001 → 4001 [ACK] Seq=153953 Ack=11(
192.168.56.103	192.168.56.105	TCP	108 4001 → 4001 [PSH, ACK] Seq=81400023
192.168.56.103	192.168.56.105	TCP	87 4001 → 4001 [PSH, ACK] Seq=81400065

Figure 34-Traffic in Wireshark for 70mb.csv file

```
0030  01 f5 2a e7 00 00 01 01  08 0a 8b 49 32 54 c0 c4
0040  06 c7 cc a2 d4 e4 a1 d2  00 fd f9 bf 86 b3 5a 98
0050  06 a3 4e 0e ec 30 59 a4  2e f1 f1 5b 0b f7 5b 5a
0060  27 29 b7 1e 6d 71 1a 6f  27 db 0c dc 3f 6c 7c 17
0070  55 4d 41 ce a5 44 cd 78  4e 37 84 37 46 1e 50 fd
0080  b7 cd b6 d4 13 95 95 73  8b 7d 55 3a c2 b1 be 6e
0090  4a 50 fa 23 a8 d6 bc 83  20 61 80 5e 91 5b 66 cf
00a0  12 1f ce 0d 62 ef 41 e4  2d 14 50 37 6b 11 80 a0
00b0  20 10 a7 bf fc 11 3d e7  3e 60 aa e2 44 0f 40 36
00c0  b4 0f 6f 80 88 43 85 50  c5 f3 65 f6 c2 fc 90 9e
00d0  b8 83 02 36 b3 6e bb 01  3b d0 1e e7 fa 44 73 d7
00e0  38 ba 7d e1 00 fe bc 47  ba d9 7f 7f 2a 31 e5 eb
00f0  ef e4 00 20 2b 9d 6f a4  48 f1 04 82 f2 fd f0 33
0100  af 20 de 97 f6 a0 c4 df  aa 2b 40 6b 4b 7a 75 fe
0110  1f bd 88 91 52 bf d6 81  49 78 bb 61 c8 86 28 e7
```

Figure 35-Encrypted data in Wireshark