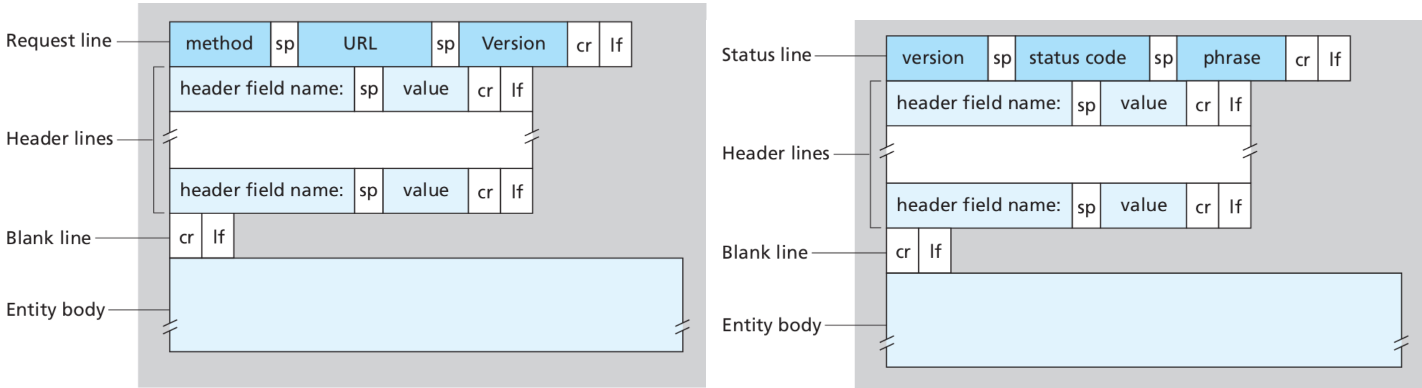
# Application Assigned : Hotstar Video Streaming
# Link for data : Drive Link

## Question 1: Protocols Used

### A) Application Layer

- **HTTP :** The protocol used in the application layer is **Hyper Text Transfer Protocol.** The HTTP messages are of two types, request and response. Request messages consist of a **request line**, followed by the **Header** and the **body** of the message. Response message format is similar but it has a **status line** instead of a request line. Request line holds the info regarding the **method** of the request, the server **URL** and the **version** of HTTP being used. Status line holds the **version**, the **status code**, and the status **phrase**. Header consists of **field name**-value pairs holding other meta information and finally the body consists of data that is sent or received.




(a) HTTP Request Message (b) HTTP Response Message

Figure 1: HTTP Message Format

- **TLSv1.2 :** TLSv1.2 is the successor of **SSL** and it provides communications security over a computer network. Symmetric cryptography is used to encrypt the data transmitted. The packet contains the type of message (handshake, alert, or data) in the '**Content Type**' field. It also contains the **version**, **length** of data and **MAC (Message Authentication Code)**.

| Byte | +0 | +1 | +2 | +3 |
|---|---|---|---|---|
| 0 | Content type | | | |
| 1..4 | Version | | Length | |
| 5..n | *Payload* | | | |
| n..m | MAC | | | |
| m..p | Padding (block ciphers only) | | | |

Figure 2: TLSv1.2 Message Format

### B) Transport Layer

**Transmission Control Protocol** is a standard that defines how to establish and maintain a network conversation via which application programs can exchange data. **Source Port** and **Destionation Port** identify the hosts of the connection, source being the end point from where the segment is sent. **Sequence Number** specifies the number assigned to the first byte of data in the current message. If the ACK control bit is set, then **Acknowledgment number** refers to the next sequence number that the sender is expecting to receive. **Data offset** specifies the size of the variable-sized TCP header. **Flags** are 1 bit values that specify the state of the connection and are used for control. **Window size** is the size of the buffer of the receiver. **Checksum** is used for error correction. Data field contains the payload of the segment.

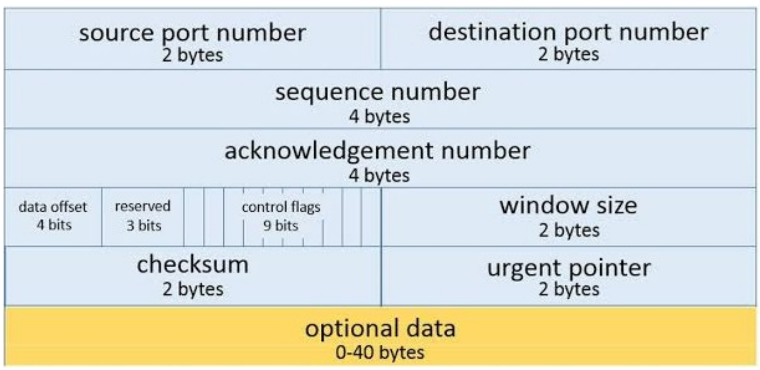



Figure 3: TCP Segment Format

### C) Network Layer

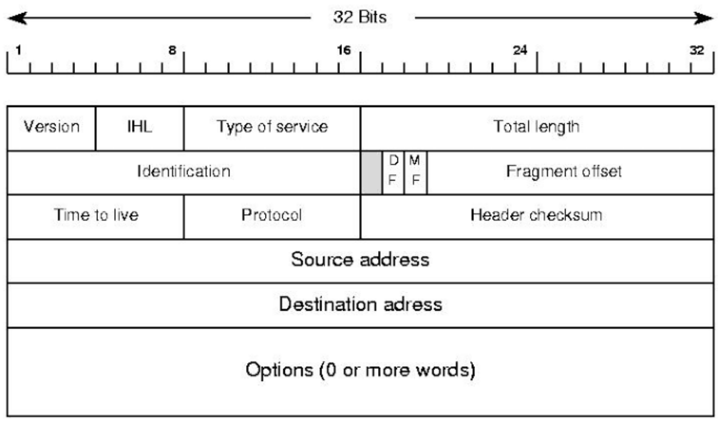



Figure 4: IP Datagram Header Format

**IPv4 (Internet Protocol Version 4)** is one of the core protocols of standards-based internetworking methods in the Internet. It is used in packet-switched networks. Each IP datagram consists of a **header** and a **data** part. The header has a 20 byte fixed part followed by a variable-sized optional part. **Version** refers to the version of the datagram. In this case it would be 4. **IHL (Internet Header Length)** is the size of the header. **Types of Service** contains a 3-bit precedence field (that is ignored today), 4 service bits, and 1 unused bit. Service bits specify what characteristics the physical layer shhould use. **Total Length** is the total length of the datagram in bytes. **Identification** uniquely identifies the datagram. All fragments of a datagram contain the same identification value. **TTL (Time to Live)** is the maximum routers through which the segment can be switched. **Protocol** indicates the next higher level protocol that is contained within the data portion of the packet. **Header checksum** is used for error detection. **Source** and **destination addresses** are the addresses of the source and destination of the packet respectively.

### D) Link Layer

**Ethernet II** is used in the link layer. **Preamble** is a 7-byte pattern of alternating 0's and 1's which indicates starting of the frame and allow the sender and receiver to establish bit synchronization. **SFD** is the start frame delimiter and marks the start of the frame. **Destination** and **source addresses** are the MAC addresses of the sending and receiving machines of the frame respectively. **Type** field is used to specify the protocol that is being used. **FCS (Frame Check Sequence)** is the error detecting code that is added.

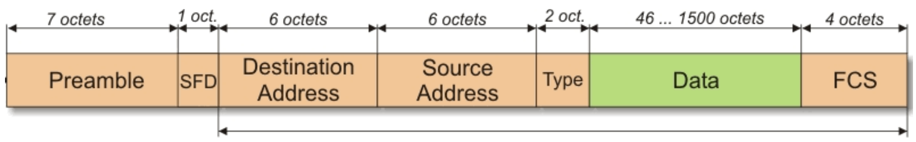
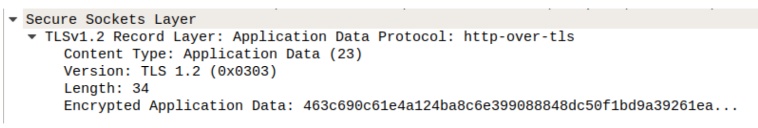



Figure 5: Ethernet Frame Format

## Question 2: Observed Values in Different Protocols

### A) Application Layer



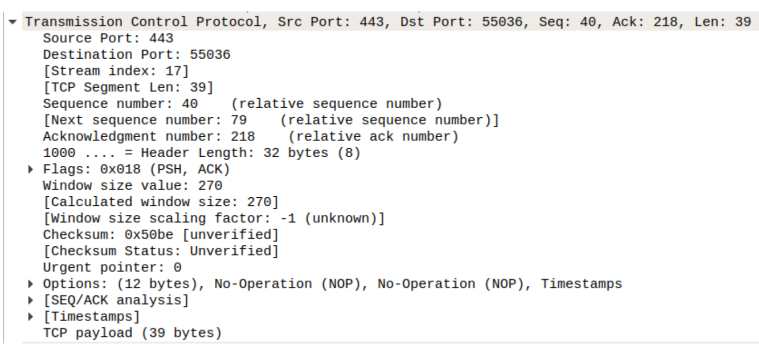
```
▾ Secure Sockets Layer
  ▾ TLSv1.2 Record Layer: Application Data Protocol: http-over-tls
      Content Type: Application Data (23)
      Version: TLS 1.2 (0x0303)
      Length: 34
      Encrypted Application Data: 463c690c61e4a124ba8c6e399088848dc50f1bd9a39261ea...
```

Figure 6: TLSv1.2 Record Example

It is visible from the example that the application data protocol is **Http-over-tls** (aka HTTPS). The **content type** in this message is Application Data. **Version** of TLS is 1.2. **Length** of the data is 34 bytes. **Encrypted Application Data** can also be seen.
HTTPS encrypts all message contents, including the HTTP headers and the request/response data, therefore no HTTP header or request/response can be seen explicitly.

### B) Transport Layer

It can be seen that the **source port** is 443 (This is to be expected because the default port for HTTPS connection is 443). The **destination port** is 55036. The **TCP Segment Length** is 39 bytes (payload). The **sequence number** is 40. **Acknowledgement number** is 218 which means that the sender of this segment is expecting a segment with sequence number 218 from the receiver. **Flags** field tells us that PSH and ACK flag is enabled. PSH flag is an option provided by TCP that allows the sending application to start sending the data even when the buffer is not full. **Window size** value is 270 (Number of packets sent before acknowledgment). The **checksum** value can also be seen that is used for error detection.



```
▾ Transmission Control Protocol, Src Port: 443, Dst Port: 55036, Seq: 40, Ack: 218, Len: 39
    Source Port: 443
    Destination Port: 55036
    [Stream index: 17]
    [TCP Segment Len: 39]
    Sequence number: 40    (relative sequence number)
    [Next sequence number: 79    (relative sequence number)]
    Acknowledgment number: 218    (relative ack number)
    1000 .... = Header Length: 32 bytes (8)
  ▸ Flags: 0x018 (PSH, ACK)
    Window size value: 270
    [Calculated window size: 270]
    [Window size scaling factor: -1 (unknown)]
    Checksum: 0x50be [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
  ▸ Options: (12 bytes), No-Operation (NOP), No-Operation (NOP), Timestamps
  ▸ [SEQ/ACK analysis]
  ▸ [Timestamps]
    TCP payload (39 bytes)
```

Figure 7: TCP Segment Example

### C) Network Layer

```
▾ Internet Protocol Version 4, Src: 180.149.60.168, Dst: 10.19.4.77
    0100 .... = Version: 4
    .... 0101 = Header Length: 20 bytes (5)
  ▸ Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
    Total Length: 91
    Identification: 0x772e (30510)
  ▸ Flags: 0x0000
    Time to live: 62
    Protocol: TCP (6)
    Header checksum: 0x05d2 [validation disabled]
    [Header checksum status: Unverified]
    Source: 180.149.60.168
    Destination: 10.19.4.77
```

Figure 8: IP Datagram Example

**Version**, as stated earlier, is 4 because IPv4 is being used. When IPv6 will be used, then the version will become 6. **Header Length** has the value 5 which implies that the header size is 20 bytes. **Total length** of the packet is 91 bytes and the **Identification number** is 0x772e. **Flag** value of 0000 implies that the datagram is not fragmented. **TTL** is 62 meaning that it can hop 62 times before dying. **Checksum** Value (0x05d2) can also be seen which is used for error detection. **Source address** (IP address of server) is 180.149.60.168. **Destination address** (IP address of my laptop) is 10.19.4.77

### D) Link Layer

The information about the **Destination** and **Source MAC addresses** can be seen. They are unique addresses assigned to the **Network Interface controllers** of the machines. The source of this frame is a Cisco device and the destination is my laptop. The **Type** of connection can also be seen.

```
▾ Ethernet II, Src: Cisco_74:60:43 (ec:44:76:74:60:43), Dst: IntelCor_52:3e:06 (ac:ed:5c:52:3e:06)
  ▾ Destination: IntelCor_52:3e:06 (ac:ed:5c:52:3e:06)
      Address: IntelCor_52:3e:06 (ac:ed:5c:52:3e:06)
      .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
      .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
  ▾ Source: Cisco_74:60:43 (ec:44:76:74:60:43)
      Address: Cisco_74:60:43 (ec:44:76:74:60:43)
      .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
      .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
    Type: IPv4 (0x0800)
```

Figure 9: Ethernet Frame Example

## Question 3: Protocols Used in Functioning of The Application

### A) Streaming

**HTTPS** (HTTP-over-TLS) is used in the Application Layer as HTTP is used by World Wide Web and defines how messages should be formatted and transmitted. **TLS** (Transport Layer Security) is a **cryptographic protocol** designed to provide communications **security** over a computer network. It **encrypts** the data and prevents hackers from **snooping**. It also prevents against **Man in the Middle** attacks. **TCP** is used at the Transport Layer as it is a **connection-oriented reliable** data transfer protocol. It offers facilities like **flow control**, **congestion control** and **error handling** mechanisms. Since the protocol is reliable, all the messages from the server reach the browser without any losses. This error-free connection is required by Hotstar because it offers very **high-quality streaming** (HD is also possible) which would not be possible otherwise. Also, the users can bo back and forth to different parts of a clip, unlike other live streaming services. IP protocol is used in the Network Layer as it is a requirement for using the Internet. IPv4 is a connectionless protocol for use on a packet-switched network. Ethernet(II) is used in the link-layer as it is one of the most widely used and reliable link layer protocol. It has **error handling** capabilities and ensures reliable data transfer between two network devices.

```
632 10.831273602  172.217.167.130   10.19.4.77        TCP       66 443 → 44404 [ACK] Seq=831 Ack=257 Win=224 Len=0 TSval=166842577 TSecr=315375348
633 10.854417192  10.19.4.77        172.217.167.130   TLSv1.2  283 Application Data
634 10.877901233  180.149.60.171    10.19.4.77        TLSv1.2  218 Server Hello, Change Cipher Spec, Encrypted Handshake Message
635 10.877928695  10.19.4.77        180.149.60.171    TCP       66 53492 → 443 [ACK] Seq=593 Ack=153 Win=30336 Len=0 TSval=1394902112 TSecr=166842579
636 10.877937824  180.149.60.171    10.19.4.77        TLSv1.2  218 Server Hello, Change Cipher Spec, Encrypted Handshake Message
637 10.877942819  10.19.4.77        180.149.60.171    TCP       66 53490 → 443 [ACK] Seq=593 Ack=153 Win=30336 Len=0 TSval=1394902112 TSecr=166842579
638 10.877944831  180.149.60.171    10.19.4.77        TLSv1.2  218 Server Hello, Change Cipher Spec, Encrypted Handshake Message
639 10.877951678  10.19.4.77        180.149.60.171    TCP       66 53494 → 443 [ACK] Seq=593 Ack=153 Win=30336 Len=0 TSval=1394902112 TSecr=166842580
640 10.878238503  10.19.4.77        180.149.60.171    TLSv1.2  117 Change Cipher Spec, Encrypted Handshake Message
641 10.881012327  172.217.163.163   10.19.4.77        TCP       66 443 → 32824 [ACK] Seq=1 Ack=593 Win=283 Len=0 TSval=1700761312 TSecr=969861328
642 10.881418421  10.19.4.77        180.149.60.171    TLSv1.2  117 Change Cipher Spec, Encrypted Handshake Message
643 10.884337535  10.19.4.77        180.149.60.171    TLSv1.2  117 Change Cipher Spec, Encrypted Handshake Message
644 10.886332414  216.58.197.74     10.19.4.77        TLSv1.2  105 Application Data
645 10.890671576  10.19.4.77        172.217.167.130   TLSv1.2  466 Application Data
646 10.892606412  10.19.4.77        180.149.60.171    TLSv1.2  544 Application Data
647 10.892613225  10.19.4.77        180.149.60.171    TLSv1.2  547 Application Data
648 10.892616826  10.19.4.77        180.149.60.171    TLSv1.2  543 Application Data
649 10.922742103  172.217.167.130   10.19.4.77        TCP       66 443 → 44404 [ACK] Seq=831 Ack=474 Win=238 Len=0 TSval=166842583 TSecr=315375387
650 10.922761917  180.149.60.171    10.19.4.77        TCP       66 443 → 53492 [ACK] Seq=153 Ack=644 Win=19584 Len=0 TSval=166842584 TSecr=1394902116
651 10.922766507  172.217.167.130   10.19.4.77        TCP       66 443 → 44404 [ACK] Seq=831 Ack=874 Win=253 Len=0 TSval=166842584 TSecr=315375423
652 10.922769337  180.149.60.171    10.19.4.77        TCP       66 443 → 53490 [ACK] Seq=153 Ack=644 Win=19584 Len=0 TSval=166842584 TSecr=1394902112
653 10.922772965  180.149.60.171    10.19.4.77        TCP       66 443 → 53494 [ACK] Seq=153 Ack=644 Win=19584 Len=0 TSval=166842584 TSecr=1394902119
654 10.929278205  10.19.4.77        216.58.197.74     TCP       66 42914 → 443 [ACK] Seq=40 Ack=40 Win=363 Len=0 TSval=359207322 TSecr=166842583
```

Figure 10: Example of Messages Transferred

### B) Pause

Just as the Pause button was pressed, a small number of packets were transmitted from the client to the server and vice versa. The content of these messages can however not be seen as TLS encrypts the message.

```
17755 168.348088643 10.19.4.77       124.124.201.232  TLSv1.2   696 Application Data
17756 168.348178682 10.19.4.77       124.124.201.232  TCP      1514 35182 → 443 [ACK] Seq=16147 Ack=3079 Win=515 Len=1448 TSval=3748876737 TSecr=186445844 [TCP segment of a reassembled PDU]
17757 168.348184651 10.19.4.77       124.124.201.232  TCP      1514 35182 → 443 [ACK] Seq=17595 Ack=3079 Win=515 Len=1448 TSval=3748876737 TSecr=186445844 [TCP segment of a reassembled PDU]
17758 168.349713833 10.19.4.77       124.124.201.232  TLSv1.2   856 Application Data
17759 168.352276872 124.124.201.232  10.19.4.77       TCP        66 443 → 35182 [ACK] Seq=3079 Ack=16147 Win=565 Len=0 TSval=186449793 TSecr=3748876737
17760 168.352290515 124.124.201.232  10.19.4.77       TCP        66 443 → 35182 [ACK] Seq=3079 Ack=17595 Win=588 Len=0 TSval=186449793 TSecr=3748876737
17761 168.352294156 124.124.201.232  10.19.4.77       TCP        66 443 → 35182 [ACK] Seq=3079 Ack=19043 Win=611 Len=0 TSval=186449793 TSecr=3748876737
17762 168.352297485 124.124.201.232  10.19.4.77       TCP        66 443 → 35182 [ACK] Seq=3079 Ack=19833 Win=633 Len=0 TSval=186449793 TSecr=3748876739
17763 168.378002586 10.19.4.77       124.124.201.232  TLSv1.2   785 Application Data
17764 168.378496625 10.19.4.77       124.124.201.232  TLSv1.2   866 Application Data
17765 168.380716071 124.124.201.232  10.19.4.77       TCP        66 443 → 35188 [ACK] Seq=1027 Ack=6531 Win=372 Len=0 TSval=186449796 TSecr=3748876767
17766 168.380805252 124.124.201.232  10.19.4.77       TCP        66 443 → 35188 [ACK] Seq=1027 Ack=7331 Win=395 Len=0 TSval=186449796 TSecr=3748876767
17767 168.424974468 10.19.5.1        10.19.7.255      UDP       305 54915 → 54915 Len=263
17768 168.459305088 124.124.201.232  10.19.4.77       TLSv1.2   579 Application Data
17769 168.459377626 10.19.4.77       124.124.201.232  TCP        66 35182 → 443 [ACK] Seq=19833 Ack=3592 Win=538 Len=0 TSval=3748876848 TSecr=186449803
17770 168.491678804 124.124.201.232  10.19.4.77       TLSv1.2   579 Application Data
17771 168.491746268 10.19.4.77       124.124.201.232  TCP        66 35188 → 443 [ACK] Seq=7331 Ack=1540 Win=455 Len=0 TSval=3748876881 TSecr=186449807
```

Figure 11: Segments Transfered on Pause

Following this **Keep Alive** segments were sent from the client to the server telling the server **not to close** the TCP connection even though no data is being currently transferred. **Acknowledgment** for those Keep Alive messages can also be seen. These Keep Alive messages are very small in size and therefore do not use much bandwidth while the video is paused. **These segments are essential otherwise the connection would be closed and no further data could be transferred even if the video is unpaused.**

| | | | | | | |
|---|---|---|---|---|---|---|
| 18019 | 192.253296404 | 10.19.4.77 | 180.149.60.171 | TCP | 66 | [TCP Keep-Alive] 35490 → 443 [ACK] Seq=60332 Ack=31027470 Win=550656 Len=0 TSval=1437485786 TSecr=186447679 |
| 18020 | 192.253333318 | 10.19.4.77 | 180.149.60.171 | TCP | 66 | [TCP Keep-Alive] 35500 → 443 [ACK] Seq=1166 Ack=4978 Win=45696 Len=0 TSval=1437485786 TSecr=186447679 |
| 18021 | 192.253347262 | 10.19.4.77 | 216.58.196.194 | TCP | 66 | [TCP Keep-Alive] 58994 → 443 [ACK] Seq=1980 Ack=3984 Win=420 Len=0 TSval=2490148958 TSecr=186447679 |
| 18022 | 192.253358587 | 10.19.4.77 | 104.244.42.131 | TCP | 66 | [TCP Keep-Alive] 45116 → 443 [ACK] Seq=497 Ack=264 Win=348 Len=0 TSval=1888175320 TSecr=186447679 |
| 18023 | 192.253368501 | 10.19.4.77 | 104.244.42.133 | TCP | 66 | [TCP Keep-Alive] 49694 → 443 [ACK] Seq=324 Ack=276 Win=348 Len=0 TSval=3108977748 TSecr=186447679 |
| 18024 | 192.253379331 | 10.19.4.77 | 151.101.8.157 | TCP | 66 | [TCP Keep-Alive] 46738 → 443 [ACK] Seq=268 Ack=154 Win=334 Len=0 TSval=472258145 TSecr=186447679 |
| 18025 | 192.253389220 | 10.19.4.77 | 104.18.100.194 | TCP | 66 | [TCP Keep-Alive] 60440 → 443 [ACK] Seq=294 Ack=1346 Win=342 Len=0 TSval=1164919619 TSecr=186447678 |
| 18026 | 192.253399613 | 10.19.4.77 | 172.217.167.230 | TCP | 66 | [TCP Keep-Alive] 50024 → 443 [ACK] Seq=1886 Ack=3016 Win=619 Len=0 TSval=238895622 TSecr=186447678 |
| 18027 | 192.253410023 | 10.19.4.77 | 216.58.221.34 | TCP | 66 | [TCP Keep-Alive] 56656 → 443 [ACK] Seq=749 Ack=2010 Win=376 Len=0 TSval=339842417 TSecr=186447678 |
| 18028 | 192.253420725 | 10.19.4.77 | 124.124.201.232 | TCP | 66 | [TCP Keep-Alive] 35190 → 443 [ACK] Seq=2675 Ack=514 Win=402 Len=0 TSval=3748900643 TSecr=186447678 |
| 18029 | 192.253430903 | 10.19.4.77 | 124.124.201.232 | TCP | 66 | [TCP Keep-Alive] 35180 → 443 [ACK] Seq=5297 Ack=1027 Win=432 Len=0 TSval=3748900643 TSecr=186447678 |
| 18030 | 192.253442236 | 10.19.4.77 | 124.124.201.232 | TCP | 66 | [TCP Keep-Alive] 35186 → 443 [ACK] Seq=9735 Ack=2476 Win=500 Len=0 TSval=3748900643 TSecr=186447678 |
| 18031 | 192.253452452 | 10.19.4.77 | 124.124.201.232 | TCP | 66 | [TCP Keep-Alive] 35184 → 443 [ACK] Seq=3151 Ack=514 Win=402 Len=0 TSval=3748900643 TSecr=186447678 |
| 18032 | 192.256217913 | 180.149.60.171 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 35490 [ACK] Seq=31027470 Ack=60333 Win=138880 Len=0 TSval=186452183 TSecr=1437395573 |
| 18033 | 192.259074019 | 216.58.196.194 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 58994 [ACK] Seq=3984 Ack=1981 Win=221 Len=0 TSval=186452183 TSecr=2489968558 |
| 18034 | 192.259109156 | 104.244.42.131 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 45116 [ACK] Seq=264 Ack=498 Win=169 Len=0 TSval=186452183 TSecr=1887994572 |
| 18035 | 192.259116975 | 172.217.167.230 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 50024 [ACK] Seq=3016 Ack=1887 Win=260 Len=0 TSval=186452183 TSecr=238715372 |
| 18036 | 192.259123987 | 180.149.60.171 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 35500 [ACK] Seq=4978 Ack=1167 Win=20608 Len=0 TSval=186452183 TSecr=1437305556 |
| 18037 | 192.259134885 | 104.244.42.133 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 49694 [ACK] Seq=276 Ack=325 Win=169 Len=0 TSval=186452183 TSecr=3108796997 |
| 18038 | 192.259141726 | 151.101.8.157 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 46738 [ACK] Seq=154 Ack=269 Win=169 Len=0 TSval=186452183 TSecr=472076635 |
| 18039 | 192.259148513 | 124.124.201.232 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 35180 [ACK] Seq=1027 Ack=5298 Win=327 Len=0 TSval=186452183 TSecr=3748719901 |
| 18040 | 192.259155055 | 124.124.201.232 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 35186 [ACK] Seq=2476 Ack=9736 Win=463 Len=0 TSval=186452183 TSecr=3748719873 |
| 18041 | 192.259161325 | 104.18.100.194 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 60440 [ACK] Seq=1346 Ack=295 Win=169 Len=0 TSval=186452183 TSecr=1164738078 |
| 18042 | 192.259167831 | 216.58.221.34 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 56656 [ACK] Seq=2010 Ack=750 Win=182 Len=0 TSval=186452183 TSecr=339661668 |
| 18043 | 192.259174442 | 124.124.201.232 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 35190 [ACK] Seq=514 Ack=2676 Win=249 Len=0 TSval=186452183 TSecr=3748719806 |
| 18044 | 192.259181007 | 124.124.201.232 | 10.19.4.77 | TCP | 66 | [TCP Keep-Alive ACK] 443 → 35184 [ACK] Seq=514 Ack=3152 Win=282 Len=0 TSval=186452183 TSecr=3748719795 |

Figure 12: Keep Alive Messages

### C) Play

Again a small number of segments are exchanged. Now the Keep Alive Messages stop though.

| | | | | | | |
|---|---|---|---|---|---|---|
| 8107 | 203.486852844 | 10.19.4.77 | 124.124.201.232 | TLSv1.2 | 785 | Application Data |
| 8108 | 203.487846644 | 10.19.4.77 | 124.124.201.232 | TLSv1.2 | 867 | Application Data |
| 8109 | 203.492554800 | 124.124.201.232 | 10.19.4.77 | TCP | 66 | 443 → 35188 [ACK] Seq=1540 Ack=8050 Win=418 Len=0 TSval=186453306 TSecr=3748911876 |
| 8110 | 203.492573399 | 124.124.201.232 | 10.19.4.77 | TCP | 66 | 443 → 35188 [ACK] Seq=1540 Ack=8851 Win=440 Len=0 TSval=186453306 TSecr=3748911877 |
| 8111 | 203.648819033 | 124.124.201.232 | 10.19.4.77 | TLSv1.2 | 579 | Application Data |
| 8112 | 203.648846804 | 10.19.4.77 | 124.124.201.232 | TCP | 66 | 35188 → 443 [ACK] Seq=8851 Ack=2053 Win=477 Len=0 TSval=3748912038 TSecr=186453317 |
| 8113 | 203.811780651 | 10.19.4.77 | 172.217.166.238 | TLSv1.2 | 355 | Application Data |
| 8114 | 203.812767423 | 10.19.4.77 | 172.217.166.238 | TLSv1.2 | 105 | Application Data |
| 8115 | 203.814744827 | 172.217.166.238 | 10.19.4.77 | TCP | 66 | 443 → 56282 [ACK] Seq=824 Ack=2242 Win=227 Len=0 TSval=186453339 TSecr=1461686994 |
| 8116 | 203.815779379 | 172.217.166.238 | 10.19.4.77 | TCP | 66 | 443 → 56282 [ACK] Seq=824 Ack=2281 Win=227 Len=0 TSval=186453339 TSecr=1461686995 |
| 8117 | 203.874724637 | 172.217.166.238 | 10.19.4.77 | TLSv1.2 | 143 | Application Data |
| 8118 | 203.874745911 | 172.217.166.238 | 10.19.4.77 | TLSv1.2 | 132 | Application Data |
| 8119 | 203.874749969 | 172.217.166.238 | 10.19.4.77 | TLSv1.2 | 105 | Application Data |
| 8120 | 203.874752662 | 172.217.166.238 | 10.19.4.77 | TLSv1.2 | 105 | Application Data |
| 8121 | 203.874816115 | 10.19.4.77 | 172.217.166.238 | TCP | 66 | 56282 → 443 [ACK] Seq=2281 Ack=1045 Win=273 Len=0 TSval=1461687057 TSecr=186453345 |
| 8122 | 203.875468975 | 10.19.4.77 | 172.217.166.238 | TLSv1.2 | 105 | Application Data |
| 8123 | 203.876873938 | 172.217.166.238 | 10.19.4.77 | TCP | 66 | 443 → 56282 [ACK] Seq=1045 Ack=2320 Win=227 Len=0 TSval=186453345 TSecr=1461687058 |

Figure 13: Segments Transfered on Play

### D) Skip 10 Seconds

Similar transfer of packets takes place between the client and the server.

## Question 4: Functionalities of the Application

### A) TCP Handshake

TCP connection is established via a **3 way handshake**. First the client sends a **SYN** segment to the server. The server responds with **ACK** for the request. It also sends a SYN in the same segment. Finally, the client responds with ACK and the connection is setup.

| | | | | | | |
|---|---|---|---|---|---|---|
| 137 | 7.132079633 | 10.19.4.77 | 103.254.155.35 | TCP | 74 | 47232 → 443 [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=3059431405 TSecr=0 WS=128 |
| 138 | 7.132656062 | 103.254.155.35 | 10.19.4.77 | TCP | 74 | 443 → 47230 [SYN, ACK] Seq=0 Ack=1 Win=18328 Len=0 MSS=9176 SACK_PERM=1 TSval=161581868 TSecr=3059431404 WS=128 |
| 139 | 7.132690938 | 10.19.4.77 | 103.254.155.35 | TCP | 66 | 47230 → 443 [ACK] Seq=1 Ack=1 Win=29312 Len=0 TSval=3059431406 TSecr=161581868 |

Figure 14: TCP Handshake

### B) Application Layer Handshake

Before the client and the server can begin exchanging application data over TLS, the encrypted tunnel must be negotiated. The client and the server must agree on the version of the TLS protocol. They must choose the ciphersuite, and verify certificates if necessary.
The first step of the handshake is **Client Hello**. Within this, the client sends a number of specifications in plain text, such as the version of the TLS protocol it is running, the list of supported **ciphersuites**, and other TLS options it may want to use.
The second step is **Server Hello**. The server picks the TLS protocol version for further communication. It decides on a ciphersuite from the list provided by the client, attaches its certificate, and sends the response back to the client. Optionally, the server can also send a request for the client's certificate and parameters for other TLS extensions.
The third step is **Client and Server Key Exchange**. Assuming both sides are able to negotiate a common version and cipher, and the client is happy with the certificate provided by the server, the client initiates either the RSA or the Diffie-Hellman key exchange, which is used to establish the symmetric key for the ensuing session.
The final step is **ChangeCipherSpec**. The server processes the key exchange parameters sent by the client, checks

message integrity by verifying the MAC (Message Authentication Code), and returns an encrypted Finished message back to the client. On the client side, the message is decrypted with the negotiated symmetric key and the MAC is verified. If all is well, then the connection is established.

| | | | | | | |
|---|---|---|---|---|---|---|
| 159 | 7.311958403 | 10.19.4.77 | 103.254.155.35 | TLSv1.2 | 679 | Client Hello |
| 160 | 7.313175589 | 103.254.155.35 | 10.19.4.77 | TCP | 66 | 443 → 47236 [ACK] Seq=1 Ack=614 Win=19584 Len=0 TSval=161581887 TSecr=3059431585 |
| 209 | 7.578291699 | 103.254.155.35 | 10.19.4.77 | TLSv1.2 | 1514 | Server Hello |
| 210 | 7.578318209 | 10.19.4.77 | 103.254.155.35 | TCP | 66 | 47232 → 443 [ACK] Seq=614 Ack=1449 Win=32128 Len=0 TSval=3059431851 TSecr=161581913 |
| 211 | 7.589801141 | 103.254.155.35 | 10.19.4.77 | TLSv1.2 | 1823 | Certificate, Server Key Exchange, Server Hello Done |
| 212 | 7.589829513 | 10.19.4.77 | 103.254.155.35 | TCP | 66 | 47232 → 443 [ACK] Seq=614 Ack=3206 Win=35712 Len=0 TSval=3059431863 TSecr=161581913 |
| 213 | 7.590766125 | 10.19.4.77 | 103.254.155.35 | TLSv1.2 | 159 | Client Key Exchange, Change Cipher Spec, Encrypted Handshake Message |

Figure 15: TLS Handshake

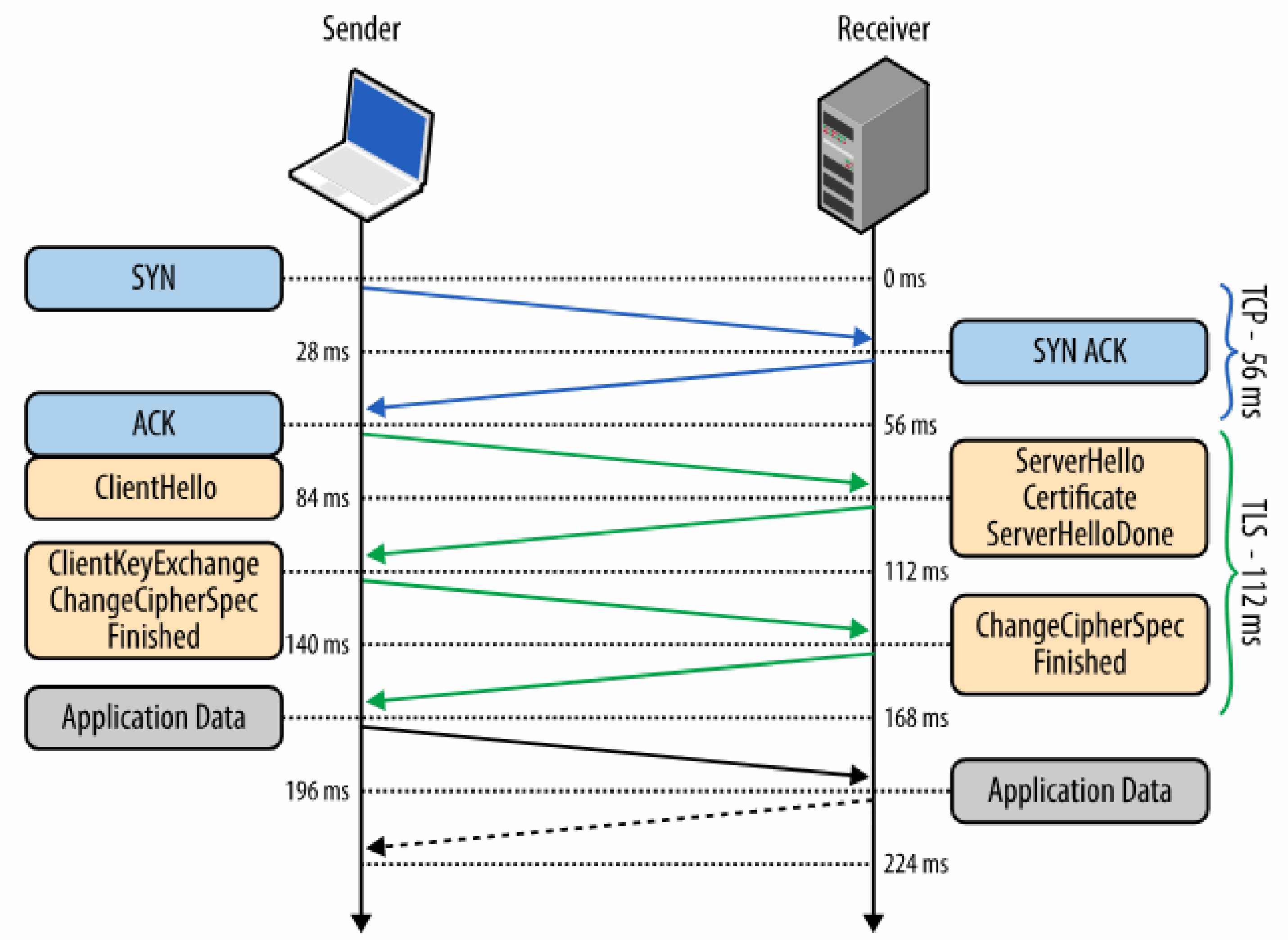



Figure 16: The Complete Picture

## C) Streaming

While streaming video, messsages are sent from the server to the client containg the information about the video. This can be seen in the image as TLS segments are labeled Application data. Some segments might be fragmented that are then joined again to form the complete message. Once the segments arrive, they are re-assembled and the payload is delivered to the application layer.

| | | | | | | |
|---|---|---|---|---|---|---|
| 3510 | 24.583799324 | 180.149.60.171 | 10.19.4.77 | TLSv1.2 | 1514 | Application Data [TCP segment of a reassembled PDU] |
| 3511 | 24.583807241 | 180.149.60.171 | 10.19.4.77 | TLSv1.2 | 1427 | Application Data |
| 3512 | 24.583949637 | 10.19.4.77 | 180.149.60.171 | TCP | 66 | 45726 → 443 [ACK] Seq=42023 Ack=4088655 Win=1885 Len=0 TSval=1368579662 TSecr=161583613 |
| 3513 | 24.602495970 | 34.201.234.134 | 10.19.4.77 | TLSv1.2 | 267 | Application Data |
| 3514 | 24.602561687 | 10.19.4.77 | 34.201.234.134 | TCP | 66 | 49696 → 443 [ACK] Seq=45290 Ack=1081 Win=749 Len=0 TSval=2303178708 TSecr=161583615 |

Figure 17: Application Data Example

## D) Pause

The message transfered on pressing pause is shown below. A small number of segments are exchanged though their content cannot be understood as TLS encrypts them.

```
17755 168.348088643 10.19.4.77        124.124.201.232   TLSv1.2   696 Application Data
17756 168.348178682 10.19.4.77        124.124.201.232   TCP      1514 35182 → 443 [ACK] Seq=16147 Ack=3079 Win=515 Len=1448 TSval=3748876737 TSecr=186445844 [TCP segment of a reassembled PDU]
17757 168.348184651 10.19.4.77        124.124.201.232   TCP      1514 35182 → 443 [ACK] Seq=17595 Ack=3079 Win=515 Len=1448 TSval=3748876737 TSecr=186445844 [TCP segment of a reassembled PDU]
17758 168.349713833 10.19.4.77        124.124.201.232   TLSv1.2   856 Application Data
17759 168.352276872 124.124.201.232   10.19.4.77        TCP        66 443 → 35182 [ACK] Seq=3079 Ack=16147 Win=565 Len=0 TSval=186449793 TSecr=3748876737
17760 168.352290515 124.124.201.232   10.19.4.77        TCP        66 443 → 35182 [ACK] Seq=3079 Ack=17595 Win=588 Len=0 TSval=186449793 TSecr=3748876737
17761 168.352294156 124.124.201.232   10.19.4.77        TCP        66 443 → 35182 [ACK] Seq=3079 Ack=19043 Win=611 Len=0 TSval=186449793 TSecr=3748876737
17762 168.352297485 124.124.201.232   10.19.4.77        TCP        66 443 → 35182 [ACK] Seq=3079 Ack=19833 Win=633 Len=0 TSval=186449793 TSecr=3748876739
17763 168.378002586 10.19.4.77        124.124.201.232   TLSv1.2   785 Application Data
17764 168.378496625 10.19.4.77        124.124.201.232   TLSv1.2   866 Application Data
17765 168.380716071 124.124.201.232   10.19.4.77        TCP        66 443 → 35188 [ACK] Seq=1027 Ack=6531 Win=372 Len=0 TSval=186449796 TSecr=3748876767
17766 168.380805252 124.124.201.232   10.19.4.77        TCP        66 443 → 35188 [ACK] Seq=1027 Ack=7331 Win=395 Len=0 TSval=186449796 TSecr=3748876767
17767 168.424974468 10.19.5.1         10.19.7.255       UDP       305 54915 → 54915 Len=263
17768 168.459305088 124.124.201.232   10.19.4.77        TLSv1.2   579 Application Data
17769 168.459377626 10.19.4.77        124.124.201.232   TCP        66 35182 → 443 [ACK] Seq=19833 Ack=3592 Win=538 Len=0 TSval=3748876848 TSecr=186449803
17770 168.491678804 124.124.201.232   10.19.4.77        TLSv1.2   579 Application Data
17771 168.491746268 10.19.4.77        124.124.201.232   TCP        66 35188 → 443 [ACK] Seq=7331 Ack=1540 Win=455 Len=0 TSval=3748876881 TSecr=186449807
```

Figure 18: Segments Transfered on Pause

**Keep Alive** segments are also sent from the client to the server as explained in the previous question. These segments and also their acknowledgments can be seen from the screenshot attached.

```
18019 192.253296404 10.19.4.77       180.149.60.171    TCP   66 [TCP Keep-Alive] 35490 → 443 [ACK] Seq=60332 Ack=31027470 Win=550656 Len=0 TSval=1437485786 TSecr=186447679
18020 192.253333318 10.19.4.77       180.149.60.171    TCP   66 [TCP Keep-Alive] 35500 → 443 [ACK] Seq=1166 Ack=4978 Win=45696 Len=0 TSval=1437485786 TSecr=186447679
18021 192.253347262 10.19.4.77       216.58.196.194    TCP   66 [TCP Keep-Alive] 58994 → 443 [ACK] Seq=1980 Ack=3984 Win=420 Len=0 TSval=2490148958 TSecr=186447679
18022 192.253358587 10.19.4.77       104.244.42.131    TCP   66 [TCP Keep-Alive] 45116 → 443 [ACK] Seq=497 Ack=264 Win=348 Len=0 TSval=1888175320 TSecr=186447679
18023 192.253368501 10.19.4.77       104.244.42.133    TCP   66 [TCP Keep-Alive] 49694 → 443 [ACK] Seq=324 Ack=276 Win=348 Len=0 TSval=3108977748 TSecr=186447679
18024 192.253379331 10.19.4.77       151.101.8.157     TCP   66 [TCP Keep-Alive] 46738 → 443 [ACK] Seq=268 Ack=154 Win=334 Len=0 TSval=472258145 TSecr=186447679
18025 192.253389220 10.19.4.77       104.18.100.194    TCP   66 [TCP Keep-Alive] 60440 → 443 [ACK] Seq=294 Ack=1346 Win=342 Len=0 TSval=1164919619 TSecr=186447678
18026 192.253399613 10.19.4.77       172.217.167.230   TCP   66 [TCP Keep-Alive] 50024 → 443 [ACK] Seq=1886 Ack=3016 Win=619 Len=0 TSval=238895622 TSecr=186447678
18027 192.253410023 10.19.4.77       216.58.221.34     TCP   66 [TCP Keep-Alive] 56656 → 443 [ACK] Seq=749 Ack=2010 Win=376 Len=0 TSval=339842417 TSecr=186447678
18028 192.253420725 10.19.4.77       124.124.201.232   TCP   66 [TCP Keep-Alive] 35190 → 443 [ACK] Seq=2675 Ack=514 Win=402 Len=0 TSval=3748900643 TSecr=186447678
18029 192.253430903 10.19.4.77       124.124.201.232   TCP   66 [TCP Keep-Alive] 35180 → 443 [ACK] Seq=5297 Ack=1027 Win=432 Len=0 TSval=3748900643 TSecr=186447678
18030 192.253442236 10.19.4.77       124.124.201.232   TCP   66 [TCP Keep-Alive] 35186 → 443 [ACK] Seq=9735 Ack=2476 Win=500 Len=0 TSval=3748900643 TSecr=186447678
18031 192.253452452 10.19.4.77       124.124.201.232   TCP   66 [TCP Keep-Alive] 35184 → 443 [ACK] Seq=3151 Ack=514 Win=402 Len=0 TSval=3748900643 TSecr=186447678
18032 192.256217913 180.149.60.171   10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 35490 [ACK] Seq=31027470 Ack=60333 Win=138880 Len=0 TSval=186452183 TSecr=1437395573
18033 192.259074019 216.58.196.194   10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 58994 [ACK] Seq=3984 Ack=1981 Win=221 Len=0 TSval=186452183 TSecr=2489968558
18034 192.259109156 104.244.42.131   10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 45116 [ACK] Seq=264 Ack=498 Win=169 Len=0 TSval=186452183 TSecr=1887994572
18035 192.259116975 172.217.167.230  10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 50024 [ACK] Seq=3016 Ack=1887 Win=260 Len=0 TSval=186452183 TSecr=238715372
18036 192.259123987 180.149.60.171   10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 35500 [ACK] Seq=4978 Ack=1167 Win=20608 Len=0 TSval=186452183 TSecr=1437305556
18037 192.259134885 104.244.42.133   10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 49694 [ACK] Seq=276 Ack=325 Win=169 Len=0 TSval=186452183 TSecr=3108796997
18038 192.259141726 151.101.8.157    10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 46738 [ACK] Seq=154 Ack=269 Win=169 Len=0 TSval=186452183 TSecr=472076635
18039 192.259148513 124.124.201.232  10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 35180 [ACK] Seq=1027 Ack=5298 Win=327 Len=0 TSval=186452183 TSecr=3748719901
18040 192.259155055 124.124.201.232  10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 35186 [ACK] Seq=2476 Ack=9736 Win=463 Len=0 TSval=186452183 TSecr=3748719873
18041 192.259161325 104.18.100.194   10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 60440 [ACK] Seq=1346 Ack=295 Win=169 Len=0 TSval=186452183 TSecr=1164738078
18042 192.259167831 216.58.221.34    10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 56656 [ACK] Seq=2010 Ack=750 Win=182 Len=0 TSval=186452183 TSecr=339661668
18043 192.259174442 124.124.201.232  10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 35190 [ACK] Seq=514 Ack=2676 Win=249 Len=0 TSval=186452183 TSecr=3748719806
18044 192.259181007 124.124.201.232  10.19.4.77        TCP   66 [TCP Keep-Alive ACK] 443 → 35184 [ACK] Seq=514 Ack=3152 Win=282 Len=0 TSval=186452183 TSecr=3748719795
```

Figure 19: Keep Alive Messages

## E) Play

Again a small number of segments are exchanged. Now the Keep Alive Messages stop though.

```
8107 203.486852844 10.19.4.77       124.124.201.232   TLSv1.2   785 Application Data
8108 203.487846644 10.19.4.77       124.124.201.232   TLSv1.2   867 Application Data
8109 203.492554800 124.124.201.232  10.19.4.77        TCP        66 443 → 35188 [ACK] Seq=1540 Ack=8050 Win=418 Len=0 TSval=186453306 TSecr=3748911876
8110 203.492573399 124.124.201.232  10.19.4.77        TCP        66 443 → 35188 [ACK] Seq=1540 Ack=8851 Win=440 Len=0 TSval=186453306 TSecr=3748911877
8111 203.648819033 124.124.201.232  10.19.4.77        TLSv1.2   579 Application Data
8112 203.648846804 10.19.4.77       124.124.201.232   TCP        66 35188 → 443 [ACK] Seq=8851 Ack=2053 Win=477 Len=0 TSval=3748912038 TSecr=186453317
8113 203.811780651 10.19.4.77       172.217.166.238   TLSv1.2   355 Application Data
8114 203.812767423 10.19.4.77       172.217.166.238   TLSv1.2   105 Application Data
8115 203.814744827 172.217.166.238  10.19.4.77        TCP        66 443 → 56282 [ACK] Seq=824 Ack=2242 Win=227 Len=0 TSval=186453339 TSecr=1461686994
8116 203.815779379 172.217.166.238  10.19.4.77        TCP        66 443 → 56282 [ACK] Seq=824 Ack=2281 Win=227 Len=0 TSval=186453339 TSecr=1461686995
8117 203.874724637 172.217.166.238  10.19.4.77        TLSv1.2   143 Application Data
8118 203.874745911 172.217.166.238  10.19.4.77        TLSv1.2   132 Application Data
8119 203.874749969 172.217.166.238  10.19.4.77        TLSv1.2   105 Application Data
8120 203.874752662 172.217.166.238  10.19.4.77        TLSv1.2   105 Application Data
8121 203.874816115 10.19.4.77       172.217.166.238   TCP        66 56282 → 443 [ACK] Seq=2281 Ack=1045 Win=273 Len=0 TSval=1461687057 TSecr=186453345
8122 203.875468975 10.19.4.77       172.217.166.238   TLSv1.2   105 Application Data
8123 203.876873938 172.217.166.238  10.19.4.77        TCP        66 443 → 56282 [ACK] Seq=1045 Ack=2320 Win=227 Len=0 TSval=186453345 TSecr=1461687058
```

Figure 20: Segments Transfered on Play

## F) TCP Connection Termination

The TCP connection termination phase uses a four-way handshake, with each side of the connection terminating independently. The client sends a FIN (piggybacked by an ACK) to the server which is ACKed by it. The server in turn sends a FIN which is ACKed by the client.

```
6643 39.287422852  10.19.4.77       103.254.155.35   TCP   66 47246 → 443 [FIN, ACK] Seq=1318 Ack=6137 Win=46080 Len=0 TSval=3059463561 TSecr=161584542
6644 39.289306541  103.254.155.35   10.19.4.77       TCP   66 443 → 47248 [ACK] Seq=1288 Ack=2118 Win=22400 Len=0 TSval=161585084 TSecr=3059463560
6645 39.289341450  103.254.155.35   10.19.4.77       TCP   66 443 → 47248 [FIN, ACK] Seq=1288 Ack=2119 Win=22400 Len=0 TSval=161585084 TSecr=3059463560
6646 39.289362892  10.19.4.77       103.254.155.35   TCP   66 47248 → 443 [ACK] Seq=2119 Ack=1289 Win=32640 Len=0 TSval=3059463563 TSecr=161585084
```

Figure 21: TCP Connection Termination

# Question 5: Statistical Analysis

The data has been collected at 3 different times of the day:-

1. **10:30 AM** in my room in Lohit using Mozilla Firefox web browser.
2. **5:00 PM** in my room in Lohit using Mozilla Firefox web browser.
3. **10:00 PM** in **Anchorenza and RadioG room** in New Sac using Mozilla Firefox web browser.

| **Statistic Name** | **10:30 (Room)** | **17:00 (Room)** | **22:00 (New Sac)** |
|---|---|---|---|
| **Throughput** | 38795.027 Bytes/sec | 217567.01 Bytes/sec | 994580.82 Bytes/sec |
| **RTT** | 40.56 ms | 9.52 ms | 0.2 ms |
| **Packet Size** | 1171.67 Bytes | 1221.18 Bytes | 1433.02 Bytes |
| **Number of Packets Lost** | 0 | 0 | 0 |
| **Number of UDP Packets** | 950 | 794 | 2180 |
| **Number of TCP Packets** | 9476 | 29635 | 41782 |
| **Number of Responses Received per Request** | 6138/3511 (1.74) | 19530/10446 (1.87) | 26376/15475 (1.70) |

Table 1: Statistical Ananlysis at 3 Different Times

Although Hotsar does not use UDP at the transport layer, UDP packets are still observed. The reason is that DNS uses UDP packets and DNS resolution is an integral part of running any web application to find its servers IP address from the given hostname.

# Question 6: Multiple Sources

The data arrived from many different IP addresses. A few of which have been listed below.

- **180.149.60.171**
- **180.149.60.168**
- **180.149.60.139**
- **124.124.201.232**
- **172.217.166.238**
- **103.254.155.35**

Most of the data arrived from the first 2 addresses. It can be seen from the attached screenshot that the canonical name for hotstar is **cname.hotstar.edgesuite.net** and the two servers are actually **Akamai** servers. Akamai is the leading **Content Delivery Network** (CDN) services provider for media and software delivery. So we can conclude that hotstar uses Akamai's services for content delivery.

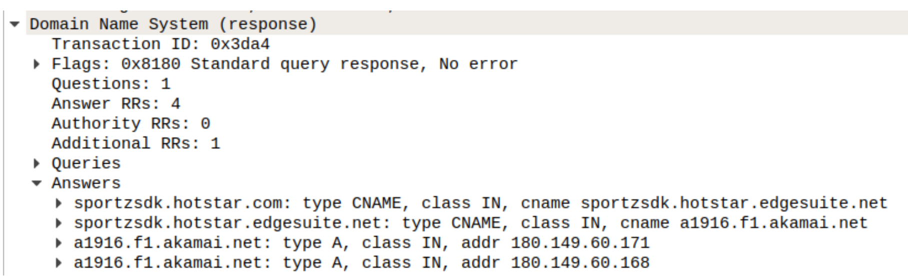



Figure 22: DNS Response

Data is sent from multiple servers because it leads to **Load Balancing**. Data comes through different paths so there is less network congestion and lesser load on each individual server. Multiple servers also lead to increased reliability as there is **no single point of failure**. Even if one server crashes, the service does not stop.