ECE257A HW1

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I. Problem 1

Explain why the Internet adopts the hierarchical architecture. Does the modern Internet follow a tree structure? Explain your answer.

Answer :

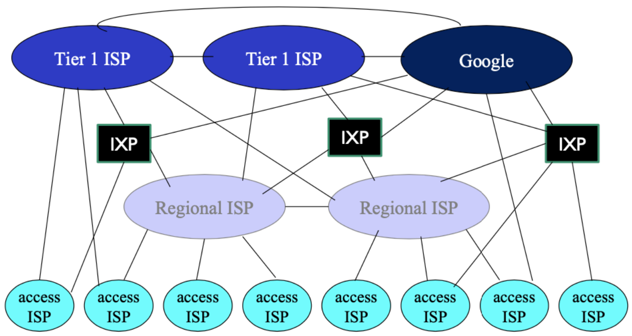

Fig. 1. Internet structure.

the Internet adopts the hierarchical architecture for reliability, scalability and ease of management.

Reliability :

The modular nature of the hierarchical network when a router or server fails it only affects a part of the network, traffic can still be routed to other routers and backup servers can still provide the service.

Scalability :

Part of the network can be added or removed without affecting much of the existing structure. This is not the case for a mesh structure, where each access ISP has to connect to another access ISP, leading to N^2 connections in total and N connections need to be established when a new ISP is added.

Ease of Management :

Each network layer has its specific role in the network, and same components have the same role. So you can deploy new switches and components with similar configurations. It is also easier to troublesboot when things go wrong.

The Internet follows a hierarchical network of network structure, with the Tier 1 ISP and content provider networks closely connected to each other, IXP and regional ISPs connected to the Tier 1 structures, and access ISPs connected to the IXP and regional ISPs. It is not a tree structure since a node of lower layer can connect to multiple nodes in the upper layer, and nodes in the same layer can connect to each other.

II. Problem 2

Quickly study the SoftRAN and SoftCell papers listed in the reference part of Lecture 02. Answer the following questions:

1) What benefits does software defined networking bring to cellular networks? Provide sufficient details to support your answer.

2) Think of one more example scenario where software defined wireless networks are superior to conventional wireless network architectures. Explain your idea. Use the hints from the papers but do not use their existing examples directly.

Answer :

1) Distributed coordination algorithms like interference and load balancing do not scale well as they need to work with larger number of base stations. They tend to be more complex and cannot get the right scale. This leads to poor performance, reducing capacity significantly. Having a centralized controller means that it can know the right scale and reduce the number of handshaking and message passing between stations. Smoother control of the centralized controller provides users with more stable connections. SoftRAN can specify a set of resource blocks and do beamforming to a particular client. It can do the resource utilization and load balancing globally to achieve better result. SoftCell handles control plane failures better than traditional network, as the controller can easily handle topology changes and and recompute the path and notify the affected switches.

2) We can dynamically adapting logical RAN architecture according to the traffic patterns. We can remap between radio elements and big-base stations and turn off some radio elements when part of the network is under-loaded to conserve power. This is possible with a centralized controller which has global view to the network at any time. It is also easier for the network to sense the breakdown if its component and reroute the traffic.

III. Problem 3

Review the Web request example we went through in Lecture 3. Suppose instead of Web browsing, the user opens a YouTube video on her smartphone. Describe the network entities (e.g., application service providers, ISPs, etc.) and devices involved in this procedure, and also describe their work flow. List the major network protocols and briefly explain their roles. Think of as many protocols as you can.

Answer :

A. Step 1: Network discovery and association

WiFi AP keeps broadcasting beacons, with its MAC address embedded in beacons. Client listens, and sends association request. Authentication and association, client connects to WiFi AP.

B. Step 2: IP address allocation - DHCP, UDP, IP, Ethernet

The smartphone client needs to get its own IP address, address of first-hop router, and address of DNS server. 1. Client creates request : OS of client's smartphone creates a DHCP request message in a UDP segment, with destination port 67 (DHCP server) and source port 68 (DHCP client). The UDP segment is further placed in an IP datagram with destination IP being broadcast address (255.255.255.255) and source IP being 0.0.0.0. The IP datagram is then placed in an Ethernet frame with destination MAC address broadcast FF:FF:FF:FF:FF:FF and source MAC address client's smartphone. The Ethernet frame is sent by client's phone to Ethernet switch and switch broadcasts to all outgoing ports.

2. The router receives the Ethernet frame, extracts the IP datagram and the UDP segment and sent it by UDP, lastly the DHCP request message is extracted and received by the DHCP server. DHCP server creates a DHCP ACK message containing the IP address allocated to client's smartphone, the IP address of the DNS server, and the IP address for the default gateway router. This DHCP ACK message is then put in a UDP segment, encapsulated in an IP datagram, and an Ethernet frame with source MAC address the router's interface and destination MAC client's phone. The Ethernet frame is sent by the router to the switch and to the client's phone.

3. Client's phone extracts the IP datagram, UDP segment, and DHCP ACK message. The client now has its IP address, IP address of the DNS server and the IP address of the default gateway router, which is put into its IP forwatding table to complete the initialization.

C. Step 3: DNS resolution - DNS and ARP

Client needs to know the IP address corresponding to URL, e.g., https://www.youtube.com/watch?.....

1. Client's smartphone's OS creates a DNS query message with "https://www.youtube.com/watch?....." in the question section. This DNS message encapsulated in a UDP segment with destination port of 53 (DNS server), and placed within an IP datagram with destination IP of the DNS server and a source IP address being its own address, both returned in the DHCP ACK. The datagram is further put in an Ethernet frame.

2. Client's phone creates an ARP query message with target IP address the default gateway, put it in an Ethernet frame with a broadcast destination address and send to the switch, which broadcast to all connected devices, including the gateway router. The gateway router receives the frame, found the target IP address in the ARP message matches its own. The gateway router then create an ARP reply with its own MAC address. The ARP message is put in an Ethernet frame with destination IP client's phone. The frame is then delivered to the switch and then client's phone.

3. Client's phone receives the frame with ARP reply message and extracts the MAC address of the gateway router. The client's phone can now finally form an Ethernet frame containing the DNS query with the gateway router's MAC address. The IP datagram has the IP destination address being the DNS server, while the frame has a destination address of the gateway router. Bob's laptop sends this frame to the switch's MAC address, which delivers the frame to the gateway router's IP.

D. Step 4: routing and TCP flow creation - RIP, OSPF, IS-IS and BGP

Establish TCP flow (end-to-end path needs to be established first through Internet routing protocol)

1. The gateway router receives the frame and extracts the IP datagram with the DNS query. The router looks up the destination IP address from its forwarding table and determines which router to send. The IP datagram is put into a link-layer frame and the frame is sent over the link. The several upcoming routers extracts and lookup the destination IP address and determines the outgoing interface. The area network's intra-domain protocol such as RIP, OSPF or IS-IS, as well as the Internet's inter-domain protocol, BGP is used.

2. Finally the datagram arrives at the DNS server. The DNS server extracts the DNS query message, looks up the name https://www.youtube.com/watch?..... in its DNS database, and finds the DNS resource record that contains the IP address. The DNS server forms a DNS reply message containing the hostname-to-IP-address mapping, put it in a UDP segment, encapsulated in an IP datagram destinated to client's smartphone. This datagram is then sent back to client's phone.

3. Client's phone extracts the IP address of the server https://www.youtube.com/watch?..... from the DNS message and is ready to contact the server.

E. Step 5: application data delivery - TCP, BGP and RMTP, HLS, DASH, RSTP

Getting Web page https://www.youtube.com/watch?.....

1. Client's phone creates a TCP SYN segment with destination port 80 (for HTTP), put it in an IP datagram with https://www.youtube.com/watch?..... server's destination IP, encapsulate in a frame with destination address gateway router's MAC, and sent to the switch to complete three-way handshake. The routers send the datagram to the https://www.youtube.com/watch?..... server using BGP protocol.

2. The https://www.youtube.com/watch?..... server extracts the TCP SYN message (Yes, Youtube uses TCP instead of UDP https://www.geeksforgeeks.org/why-is-youtube-using-tcp-but-not-udp/)sand a TCP connection socket is created between its HTTP server and client's phone. A TCP SYNACK message is created, put in a datagram destinated to client's phone and placed in a link-layer frame to routers.

3. The datagram containing TCP SYNACK message is demultiplexed in client's phone's TCP socket and enters the connected state. The client's phone then creates a DASH

(Dynamic Adaptive Streaming over HTTP) GET message with the URL. The message is then written in the socket and becomes a payload of a TCP segment, which is futhur put in a datagram and sent to the server. Note that protocols like RMTP(Real-Time Messaging Protocol), HLS(HTTP Live Streaming), DASH(Dynamic Adaptive Streaming over HTTP), RSTP(Real-Time Streaming Protocol) can also be used.

4. The server reads the GET message from its TCP socket, generates DASH response messages with the requested video packets inside and sends the messages to the TCP socket. The client's phone receives the messages, extract the packets and display it for the Youtube video.

IV. Problem 4

Understand wireless network performance metrics.

1) Does higher network throughput always mean lower latency? Why?

2) Why higher network density improves per-user link capacity in general? Will the total capacity of a wireless network keep increasing if more and more base stations are deployed in the same area?

3) Besides more efficient hardware, how do wireless communication devices reduce their power consumption?

Answer:

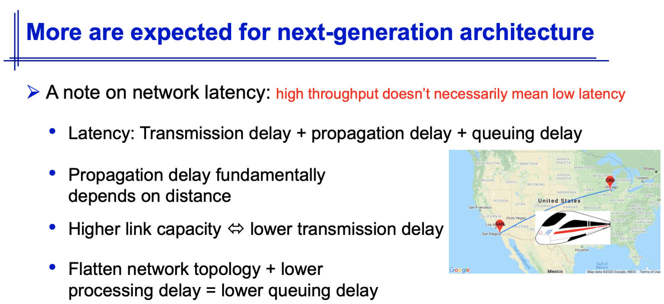

Fig. 2.

1) No. Latency = Transmission delay + propagation delay + queuing delay. Propagation delay fundamentally depends on distance and higher throughput means lower transmission delay but doesn't affect the propagation delay so the latency can still be high if distance is far.

2) Higher network density increases the coverage of the network hence improves the per-user link capacity. Since the network traffic share the same medium of transmission that is the channel in air, the same amount of channel in air cannot keep increasing even in the base stations increase so the total capacity of a wireless network doesn't keep increasing if more and more base stations are deployed in the same area.

3) Better sleep scheduling protocols, sleeping when idle. Reduce the frequency of the beaconing signal. Turning off the 5Ghz band.

V. Problem 5

Understand wireless propagation.

1) Does wireless signal strength always get weaker as link distance increases? Why?

2) Suppose a 30 GHz transmitter and a 3 GHz transmitter send signals at the same power level, estimate the difference between the received signal power (assuming link distance and antenna gains are the same).

3) Suppose a transmitter increases its transmit power by 10 dB, how will the transmission range increase? How about 3 dB? (Provide a coarse estimation.)

4) How does multipath reflection cause frequency-selective fading (i.e., channel gain various across different frequencies)?

5) Coherence time is a metric to quantify how stable the wireless channel over time. Intuitively, it is a time-domain metric. But why is it related to the Doppler shift which is a frequency-domain metric?

Answer:

1) No. In practice, channel gain = pathloss + small scale fading. The pathloss gets weaker as link distance increases, but with small scale fading the signal strength is not always weaker as distance increase.

2)

$$P_r = G_r G_t (\frac{\lambda}{4\pi d}^2) P_t$$

So the 30 GHz transmitter's signal end up to have $\frac{1}{100}$ of the 3 GHz transmitter's signal power.

3) The transmission range increase by $\sqrt{10}$ times when the transmit power increases by 10 dB, and by $\sqrt{2}$ times when the transmit power increases by 3 dB.

4) The multipath signals strengthen each other when they arrive at a place in phase, and weakens the peak size of the signal when they arrive the place out of phase. When certain frequency causes the multipath signals arrive the place the out of phase, frequecy-selective fading occurs.

5) As the velocity increases, the channel changes faster that affect the distortion so the coherence time decreases. Doppler shift is proportional to the velocity, so when it increases the coherence time decreases.

VI. Problem 6

DSSS modulation.

1) Explain how DSSS modulation improves the link SNR compared with the case without spreading.

2) Explain how DSSS modulation realizes 250 Kbps bit rate over a 2MHz channel for ZigBee, and how it realizes 1 Mbps bit rate over a 22 MHz channel for 802.11b.

Answer:

1) The amplitude of the noise becomes $\frac{1}{N}$ when de-spreading occurs and the amplitude of signal recovers to its original amplitude after spreading and de-spreading, so the noise is degraded to $\frac{1}{N}$, where N is the length of the chip sequence. If without spreading, the amplitude of the noise will not recover to its original amplitude after de-spreading.

2) Zigbee : every 4 bits form a symbol, and each symbol is mapped to a 32 bit chip sequence. So $250Kbp \rightarrow 62.5kS/s \rightarrow 2MChips/s$. The signal is later modulated with O-QPSK (orthogonal QPSK) modulation and sent out

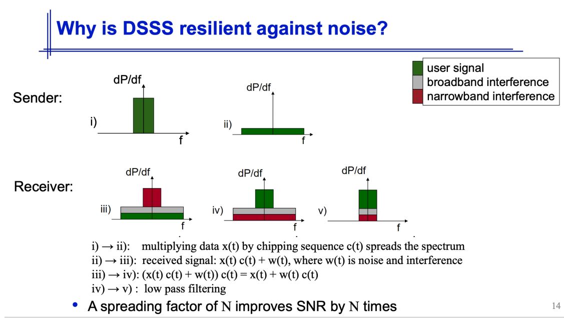

Fig. 3.

I phase (real) and Q phase (imaginary) signals are sent out simultaneously. The sampling period is $0.5\mu S$, so bandwidth is $1/0.5MHz = 2MHz$.

802.11b : Each chip is modulated into baseband waveforms, using DBPSK. On the waveform 2 samples (I and Q) represent 1 chip, with chip rate 11 MHz. This yields sampling rate 22Mbps and bandwidth 22 MHz, with bit-rate 1Mbps.

VII. Problem 7

A. Magnitude of the samples in STF

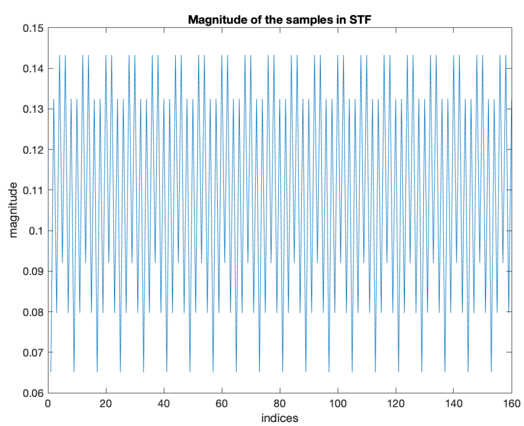

Fig. 4. Magnitude of the samples in STF.

B. Power spectrum density of the OFDM data symbols

C. Magnitude of samples in STF after distortion

D. Self-correlation results

Indices of samples corresponding to the STF region :

E. Cross-correlation results

Indices of samples corresponding to the STF starting time for each packet :

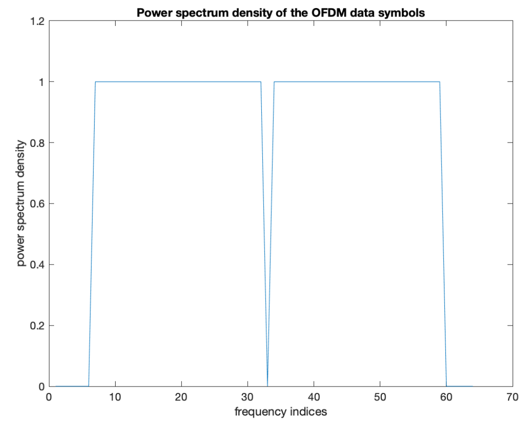

Fig. 5. Power spectrum density of the OFDM data symbols.

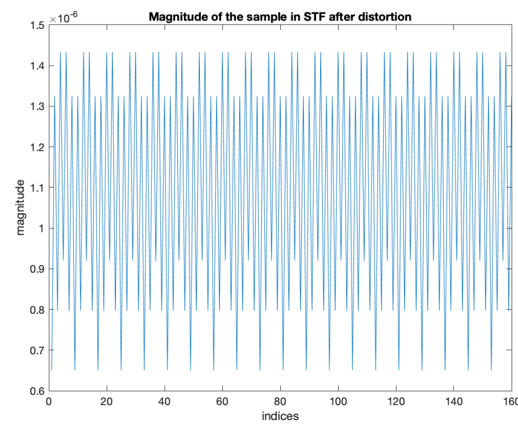

Fig. 6. Magnitude of samples in STF after distortion.

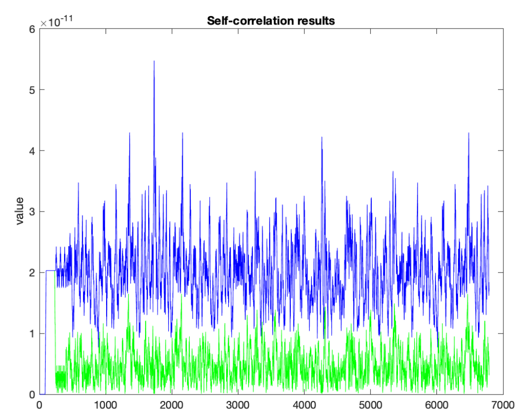

Fig. 7. Self-correlation results.

```
Indices of STF region:
  Columns 1 through 22

  101   102   103   104   105   106   107   108   109   110   111   112   113   114   115   116   117   118   119   120   121   122

  Columns 23 through 44

  123   124   125   126   127   128   129   130   131   132   133   134   135   136   137   138   139   140   141   142   143   144

  Columns 45 through 66

  145   146   147   148   149   150   151   152   153   154   155   156   157   158   159   160   161   162   163   164   165   166

  Columns 67 through 88

  167   168   169   170   171   172   173   174   175   176   177   178   179   180   181   182   183   184   185   186   187   188

  Columns 89 through 110

  189   190   191   192   193   194   195   196   197   198   199   200   201   202   203   204   205   206   207   208   209   210

  Columns 111 through 132

  211   212   213   214   215   216   217   218   219   220   221   222   223   224   225   226   227   228   229   230   231   232

  Columns 133 through 154

  233   234   235   236   237   238   239   240   241   242   243   244   245   246   247   248   249   250   251   252   253   254

  Columns 155 through 160

  255   256   257   258   259   260
```

Fig. 8. Indices of STF region.

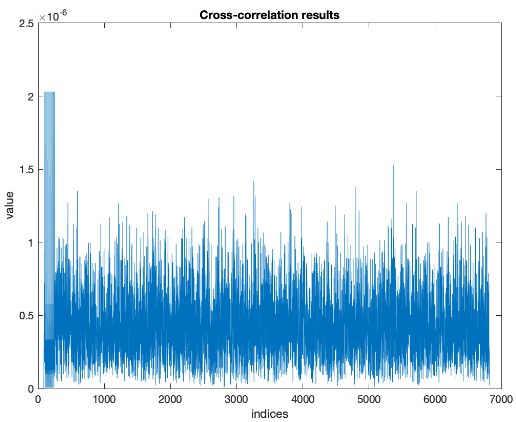

Fig. 9. Cross-correlation results.

```
Indices of STF starting time:
    101   117   133   149   165   181   197   213   229   245
```

Fig. 10. Indices of STF starting time.

```
Estimated Frequency Offset: 0.000170
```

Fig. 11. Estimated frequency offset.

```
Channel Distortion:
   1.0e-05 *

  Columns 1 through 6

   0.0000 + 0.0000i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 7 through 12

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 13 through 18

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 19 through 24

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 25 through 30

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i

  Columns 31 through 36

   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i
```

Fig. 12. Channel Distortion 1.

```
  Columns 31 through 36

   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i

  Columns 37 through 42

   0.0000 + 0.0000i   0.0000 + 0.0000i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 43 through 48

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 49 through 54

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 55 through 60

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i

  Columns 61 through 64

  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i  -0.7073 - 0.7069i
```

Fig. 13. Channel Distortion 2.

```
Transmitted Strings:
  c-Ã  Óõe77}À  X  ·ùh:Á ?£28   á  ßÄãT§#ÓüCj 5HÈÄ/oS9ç`Ür     €òê«  _üª ·²>ÀSõp¿
  ×ó¹m«½  ù®u  S*Z`  `ìÊy2Ø|¯'íPT  ¨
Cý~Ë
#+  å   ÷ª®¢½  _    ¨  ·   2ëÀ-^Ê³  ÖT   Të
ëÕè\í  Ä´ôÕm  vßÑë|¬¸ç>  ;-  F      ï!<1ÿ   ¡<ß> õ{/(Vùyc;  í±A  ¬Ô  Îÿ  ZÕò·,ÝýÜ\Ý
   f 2  IüóP-ªÕQ  9d;þ;. 8  3y½Bjtä$$bX$Ø:£Ý(zT  'E  ec:ÅÎ  ðs¥û¶   ÀªE   §W]Ï\ô
ÖoçOaá7 Ïª¼Í
æÉy$Ö*  ~»³B  q}Ô1     €5¬#O  b
B=º}¾  ?  ¢³!á  Rr  u·L  &½ï9¬ô¯_ÃÚJ
  óÇÖ¦0mHðvÏ4$      l  ¼:ßìÐ»n _ygt4FÄ½bDï®8€|  íA¦  ÕTP  ýæäL¨¹õT
¸Âuýó¨¨ HZ÷Ô  g:a
```

Fig. 14. Transmitted String.

F. Estimated frequency offset

G. Channel distortion to each subcarrier

H. Resulting characters

Transmitted String:
Received String:
Error rate : 0%

```
Received Strings:
  c-Ã  Óõe77}À  X  ·ùh:Á ?£28   á  ßÄãT§#ÓüCj 5HÈÄ/oS9ç`Ür     €òê«  _üª ·²>ÀSõp¿
  ×ó¹m«½  ù®u  S*Z`  `ìÊy2Ø|¯'íPT  ¨
Cý~Ë
#+  å   ÷ª®¢½  _    ¨  ·   2ëÀ-^Ê³  ÖT   Të
ëÕè\í  Ä´ôÕm  vßÑë|¬¸ç>  ;-  F      ï!<1ÿ   ¡<ß> õ{/(Vùyc;  í±A  ¬Ô  Îÿ  ZÕò·,ÝýÜ\Ý
   f 2  IüóP-ªÕQ  9d;þ;. 8  3y½Bjtä$$bX$Ø:£Ý(zT  'E  ec:ÅÎ  ðs¥û¶   ÀªE   §W]Ï\ô
ÖoçOaá7 Ïª¼Í
æÉy$Ö*  ~»³B  q}Ô1     €5¬#O  b
B=º}¾  ?  ¢³!á  Rr  u·L  &½ï9¬ô¯_ÃÚJ
  óÇÖ¦0mHðvÏ4$      l  ¼:ßìÐ»n _ygt4FÄ½bDï®8€|  íA¦  ÕTP  ýæäL¨¹õT
¸Âuýó¨¨ HZ÷Ô  g:a
```

Fig. 15. Received String.