Putting it all together...

• What happens when a user shows up to a new network and wants to access a web site?

(These are new slides. Please stop and ask questions if anything is unclear!)
Scenario

Network: 1.0.0.0/24
24 bits: network
8 bits: host

Network: 5.0.0.0/16
16 bits: network
16 bits: host
Before anyone starts sending data, we’ll assume the routers have run a routing protocol (BGP) to learn about each other.

Send to me to get to 1.0.0.0/24!
Step 0: Routing Protocol

Before anyone starts sending data, we’ll assume the routers have run a routing protocol (BGP) to learn about each other.
Step 1: User Joins Network

User arrives and needs an IP address. They bring MAC address with them (built in to hardware).
Step 1: User Joins Network

User broadcasts DHCP DISCOVER message to acquire IP address. (Alternative, they manually enter IP config details.)
Step 1: User Joins Network

DHCP responds with: IP address (1.0.0.15), subnet mask (255.255.255.0), gateway (1.0.0.1), and DNS server (1.0.0.2).
Step 2: User Resolves Name Name

Suppose user tries to access website: www.xkcd.com. Must resolve name using DNS. Query local resolver.
Step 2: User Resolves Name

User’s PC must answer: is the DNS resolver (1.0.0.2) I was given by DHCP on my subnet? (Local vs. Internet)

1.0.0.15: 255.255.255.0:

ANDed together: my network prefix

Match! It’s local. Send directly, no need to go through Internet gateway (router).
Step 2: User Resolves Name

User’s PC does NOT know DNS server’s MAC address!
Broadcast ARP request looking for 1.0.0.2!
Step 2: User Resolves Name

DNS server responds with MAC address.

<table>
<thead>
<tr>
<th>IP Address</th>
<th>MAC Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0.0.2</td>
<td>00:AA:BB:CC:DD:FF</td>
</tr>
</tbody>
</table>

DHCP  DNS

1.0.0.2

Internet

www.xkcd.com
Step 2: User Resolves Name

User queries local DNS resolver for www.xkcd.com. Resolver runs necessary queries (root, TLD, etc.)
Step 2: User Resolves Name

DNS reply says that www.xkcd.com is 5.0.9.25.
Step 3: Establish a TCP Connection

User’s PC must answer: is the destination (5.0.9.25) on my subnet? (Local vs. Internet)

my address
1.0.0.15: 00000001 00000000 00000000 00001111
255.255.255.0: 11111111 11111111 11111111 00000000

ANDed together:
my network prefix: 00000001 00000000 00000000

target address
5.0.9.25 00000101 00000000 00011001 00011101

No Match! Send it to the default gateway (router that connects to the Internet) that DHCP gave us (1.0.0.1).
Step 3: Establish a TCP Connection

User’s PC does NOT know router’s MAC address! Broadcast ARP request looking for 1.0.0.1!
Step 3: Establish a TCP Connection

Router responds with MAC address.

<table>
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<td>10.0.0.2</td>
<td>00:AA:BB:CC:DD:FF</td>
</tr>
<tr>
<td>10.0.0.1</td>
<td>00:00:11:11:22:22</td>
</tr>
</tbody>
</table>
Step 3: Establish a TCP Connection

Send TCP SYN to the destination, start 3-way handshake.

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Step 3: Establish a TCP Connection

Send SYN to router.
NOTE: while the switch moves the frame to router, it is not ever addressed directly.
Step 3: Establish a TCP Connection

Router removes Ethernet header.

DHCP  DNS
1.0.0.2

1.0.0.15
00:01:02:03:04:05

www.xkcd.com
Step 3: Establish a TCP Connection

Router $R_1$ compares destination IP with its forwarding table, looks for longest prefix match.

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Output Port</th>
<th>Next Router’s Link Layer Addr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0.0.0/24</td>
<td>A</td>
<td>(N/A - no router there)</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>5.0.0.0/8</td>
<td>B</td>
<td>Some Internet router’s address</td>
</tr>
<tr>
<td>5.0.0.0/16</td>
<td>C</td>
<td>$R_2$’s Address: 55:44:33:22:11:00</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Best match: 5.0.0.0/16 -> Output port C
Step 3: Establish a TCP Connection

Router $R_1$ constructs frame and forwards it to $R_2$. 

DHCP  DNS  

Link Layer Header  IP Header  TCP Header  
Dest MAC: 55:44:33:22:11:00  Dest IP: 5.0.9.25  Dest port: 80 SYN  

1.0.0.1  1.0.0.2  5.0.0.1  

1.0.0.15  00:01:02:03:04:05  

www.xkcd.com
Step 3: Establish a TCP Connection

Router $R_2$ compares destination IP with its forwarding table, looks for longest prefix match.

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<td>$R_1$’s Address</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Best match: 5.0.0.0/16 -> Output port C
Destination MAC: ?
Step 3: Establish a TCP Connection

R₂ does NOT know destination’s MAC address!
Broadcast ARP request looking for 5.0.9.25!
Data packet is queued while waiting for ARP to resolve.

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<th>MAC Address</th>
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<tr>
<td>5.0.9.25</td>
<td>?</td>
</tr>
</tbody>
</table>
Step 3: Establish a TCP Connection

Host replies with MAC address.

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<th>MAC Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0.9.25</td>
<td>AA:BB:CC:DD:EE:FF</td>
</tr>
</tbody>
</table>
Step 3: Establish a TCP Connection

R₂ constructs frame, forwards it to destination.
Mission Accomplished!

Destination peels off headers, generates reply (SYN+ACK).
Mission Accomplished!

Process repeats in the opposite direction, without the ARPs this time. (MAC addresses were recently used, thus cached.)
Steady State

• With DNS cached and ARP entries cached, host encapsulates data in TCP, IP, Eth headers and sends to router. Router forwards.

• Even *with* all the DNS/ARP, all that stuff happens in < 1 second
  (besides step 0: routing protocol)