Networking

“Robotics is networking.”
– Liam Paull, co-inventor of Duckietown and professor at University of Montreal
Programs

- nc (netcat)
- nmap
- traceroute
- ping
- whois
- wireshark
- iftop
Connecting to Your Robot
OSI Model

7. Application Layer
6. Presentation Layer
5. Session Layer
4. Transport Layer
3. Network Layer
2. Data link Layer
1. Physical Layer
Physical Layer

- Voltages, impedance, cables.
- Transmitting raw bits.
- Examples?
Ethernet

- Twisted pair wiring.
- 10BaseT – two differential voltages, 2.5v or -2.5v.
- Lots of variants to make things go faster.
Why are there five wires?

- Full-Duplex vs. Half-Duplex
- Phones?
  - Full
- VHF Radio?
  - Half
Ethernet – Physical Layer

• What does it hide?
  – Voltage wiggles on the wire.

• How does it leak?
  – Broken connections.
  – Noise caused by interference, long cables, etc.
Wifi – Physical Layer

- RF frequency modulation encodes bits. (802.11ac b/g/n)
- Bits represent a packet with a header, MAC address, content, checksum.
- Raspberry Pi has the BCM43438
  - Single-Chip IEEE 802.11ac b/g/n MAC/Baseband/Radio with Integrated Bluetooth 4.1 and FM Receiver

- What does it hide?
  - RF frequency modulation to encode data.
  - Transmission/sending/channel etc.

- How does it leak?
  - Noise from interference.
802.11

• SSID - “Name” of wireless network.

• Network modes
  - Ad-hoc – peer to peer connections
  - Master – you are the master, and connect to other nodes that you manage (you decide SSID, passwords, etc).
  - Managed – you connect to some other access point who is the master.

• Security.
Noise!
OSI Model

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MAC address

- Media Access Control
- Checksums
- Each NIC has its own globally unique MAC address.
- Ethernet Datagrams
## Ethernet Datagram

<table>
<thead>
<tr>
<th>Layer</th>
<th>Preamble</th>
<th>Start of frame delimiter</th>
<th>MAC destination</th>
<th>MAC source</th>
<th>802.1Q tag (optional)</th>
<th>Ethertype (Ethernet II) or length (IEEE 802.3)</th>
<th>Payload</th>
<th>Frame check sequence (32-bit CRC)</th>
<th>Interpacket gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 2</td>
<td>7 octets</td>
<td>1 octet</td>
<td>6 octets</td>
<td>6 octets</td>
<td>(4 octets)</td>
<td>2 octets</td>
<td>46-1500 octets</td>
<td>4 octets</td>
<td>12 octets</td>
</tr>
<tr>
<td>Ethernet frame</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethernet packet &amp; IPG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Access on Windows: Start → Run → \readyshare
Exercise!

- What is your computer’s (wifi or ethernet) mac address?
  - `ifconfig`

- What is your phone’s wifi MAC address?
  - There might be an app or a way in settings. (In Android, it’s in “Advanced Wi-Fi Settings”.)
  - Set up internet connection sharing; connect with your base station; run `iwconfig`. 
Ethernet – Data Link Layer

• What does it hide?
  – Bits can get flipped by the physical layer.

• How does it leak?
  –
stefie10@titanic:~
$ ifconfig enp60s0
enp60s0   Link encap:Ethernet  HWaddr a4:4c:c8:5d:6d:d2
          UP BROADCAST MULTICAST  MTU:1500  Metric:1
          RX packets:0  errors:0  dropped:0  overruns:0  frame:0
          TX packets:0  errors:0  dropped:0  overruns:0  carrier:0
          collisions:0  txqueuelen:1000
          RX bytes:0 (0.0 B)  TX bytes:0 (0.0 B)
          Interrupt:16
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IP

- Internet Protocol!
  - “The Internet Protocol (IP) is the principal communications protocol in the Internet protocol suite for relaying datagrams across network boundaries. Its routing function enables internetworking, and essentially establishes the Internet.” - Wikipedia

- IP Address
  -
10.*.*.* - VPNs
192.168 - private
Exercise

- What is your phone’s IP address?
- What is your computer’s IP address?
Routing

- Routing Table
  - Each device has a table.
Exercise

- What is your computer’s routing table?
  - ‘route’ on linux

```
$ route
Kernel IP routing table
Destination    Gateway         Genmask      Flags Metric Ref Use Iface
default        192.168.1.1     0.0.0.0      UG    600   0    0 wlp61s0
link-local     *                255.255.0.0  U     1000  0    0 docker0
172.17.0.0      *                255.255.0.0  U      0    0    0 docker0
192.168.1.0     *                255.255.255.0 U      600   0    0 wlp61s0
```
Connecting to the Interwebs

- Hub
- Switch
- Router
- Gateway
Exercise

• What is the route between you and Google?
Traceroute

```
$ traceroute h2r.cs.brown.edu
traceroute to h2r.cs.brown.edu (128.148.36.119), 30 hops max, 60 byte packets
  1 10.50.104.1 (10.50.104.1)  8.044 ms  9.491 ms  9.098 ms
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  5 border2.aee-edgenet.wdc002.pnap.net (66.150.117.21)  72.885 ms  96.584 ms  72.850 ms
  6 core2.tes-2-bbn.etnet.wdc002.pnap.net (216.52.127.72)  72.853 ms  94.238 ms  94.158 ms
  7 bbri.ae4.trapvax9-9.wdc002.pnap.net (64.95.159.246)  105.565 ms  87.411 ms  94.142 ms
  8 bbri.ae2.wdc002.pnap.net (64.95.159.33)  117.210 ms  bbri.ae1.wdc002.pnap.net (64.95.159.29)  94.079 ms  137.217 ms
  9 eqc-exchange.tr01-asbroad1.transitrail.net (206.126.236.45)  129.277 ms  132.963 ms  132.959 ms
  10 eh-0-8.rtsw.newy32aoo.net.inten2.edu (64.57.21.235)  129.188 ms  132.835 ms  132.850 ms
  11 198.71.47.58 (198.71.47.58)  132.817 ms  224.644 ms  219.469 ms
  13 host-198.7-224-110.oshean.org (198.7.224.110)  185.238 ms  185.207 ms  host-198.7-224-106.oshean.org (198.7.224.106)  127.991 ms
  14 131.109.200.2 (131.109.200.2)  127.977 ms  101.843 ms  126.259 ms
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Amtrak
IP (Internet Protocol)

- MAC address to IP Address
- Routing

- What does it hide?
  - Network connectivity graph.
  - Routing.
  - Disconnection of one route; connecting via a different route.

- How does it leak?
  - Cycles.
  - No path to host.
  - Dropped packets.
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UDP (User Datagram Protocol)

- Host-to-host connectivity
- Ports
- Checksums
- Lost packets, duplicate packets, out-of-order packets might happen!
- What does it hide?
  - Checksums
- How does it leak?
  - Won’t work if disconnected.
TCP/IP

- Transmission Control Protocol
TCP (Transmission Control Protocol)

• Host-to-host connectivity.
• Ports!
• Open Socket, Close Socket, make it look like a file.
• What does it hide?
  – Lost packets
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• How does it leak?
  – Accurate delivery, not timely delivery.
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Presentation Layer

• ASCII vs. EBCDIC
• Other stuff.
• I have never used it.
Session Layer

• Managing opening, closing, managing sessions.
• I have never used it.
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Application Layer

- HTTP
- SSH
- SSH
- FTP
- SMTP
- ....
DNS (Domain Name System)

- World-wide system for mapping IP addresses to names.
- I pay godaddy.com for the domain name, and pair.com to run a DNS server and host a public website.

What does it hide?
- IP addresses are ugly numbers.

How does it leak?
- The public internet has a complicated DNS system that you have to buy into. You often want DNS on your LAN but it won’t translate into the public internet. Also setting up a DNS on a LAN is work and many routers don’t do it by default.
Exercise

- Who owns stellex.org?
DHCP (Dynamic Host Configuration Protocol)

- Connect to a new network.
- Ask the world for an IP address
  - Protocol: UDP
- What does it hide?
  - You don’t actually have an IP address at first.
  - You don’t have to configure other network settings, like the gateway or the broadcast mask.
- How does it leak?
  - If no DHCP server, no IP address.
Problems

- Connect two computers?
- Send data to another network?
- Dropped packets?
- Fast transmission?
- How do we use names instead of IP addresses?
- Obtaining an initial IP address?
- How do we share one IP address?
- How do we talk to the robot?
NAT (Network Address Translation)

• IP addresses are expensive!
  – My Comcast: $40/month
  – My T-Mobile bill: $57/month

• Lets you share one IP address with lots of people.

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- Convention for organization of software on the file system for compiling and running (dependency management).

- Library of useful robot software. (Transforms, filters, visualization, etc.).
Design Scenario

- You want to connect to the drone with your base station.
- Our solution
  - The Pi acts as an 802.11 Master node and advertises a public but password protected network.
  - The Pi runs a DHCP server and allocates IP addresses to anyone who connects to the network.
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- Wins:
  - Can start the Pi and connect and don’t need to talk to CIS.
  - Works anywhere!
- Cons:
  - Pi does not have an internet uplink. No “git pull”!
  - Possible network interference.
  - Need to change Wifi settings when setting up a new Pi so there is no name collision.
Design Scenario

• You want to set up a network in your house and enable your cell phone, laptop, and desktop to connect to it.

• My solution
  – Pay Comcast for one IP address and a cable modem.
  – Purchase a WIFI Router.
  – Connect router “uplink” to cable modem.
  – Connect router LAN to desktop.
  – Connect router WIFI link to cell phone and laptop.
  – Router will run DHCP server to allocate IP addresses on LAN.

• Wins:
  – I only pay for one IP address.
  – All “my” machines are behind the NAT and can’t be hacked without first hacking the router.

• Cons:
  – I can’t be a server. Had to do gymnastics to play Minecraft with my brother-in-law.
Open Questions

• The drone has a DHCP server but no Dynamic DNS set up. How do you set up dynamic DNS on the drone so you can ping by hostname as well as by IP address?

• What is the best way for 25 drones and base stations to run at the same time?

• What is the best way to give the drone internet access?
Debugging Strategies

- Decompose the problem.
  - Verify each sensor is sending data.
  - Verify the power chain.
  - Verify motor actuation works.

- Visualize the state.
  - Visualize sensor data.
  - Cleanflight and Javascript API.

- Break the abstraction barriers.
  - Multimeter to check power/connectivity.

- Slow things down.
  - Write sensor logs to a file and graph them.
  - Insert sleep/break statements to pause execution.
Networking

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Connecting to Your Robot
Networking Jargon

- TCP (Transmission Control Protocol)
- IP (Internet Protocol)
- UDP (User Datagram Protocol)
- DNS (Domain Name System)
- DHCP (Dynamic Host Configuration Protocol)
- NAT (Network Address Translation)
- Gateway
- IP Address
- MAC Address (Media Access Control Address)
- Port
- Router
- Hub
- Switch
- AP (Access Point)
- Master vs Managed
- SSID (Service Set Identifier)
Wifi!

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 18  ***
 19  ***
 20  ***
 21  ***
 22  ***
 23  ***
 24  ***
 25  ***
 26  ***
 27  ***
 28  ***
 29  ***
 30  ***
```

Amtrak

60
Traceroute
### Ping

#### IPv4 Datagram

<table>
<thead>
<tr>
<th>Field</th>
<th>Bits 0–7</th>
<th>Bits 8–15</th>
<th>Bits 16–23</th>
<th>Bits 24–31</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Header</strong> (20 bytes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version/IHL</td>
<td></td>
<td>Type of service</td>
<td>Length</td>
<td></td>
</tr>
<tr>
<td>Identification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time To Live (TTL)</td>
<td></td>
<td>Protocol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source IP address</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination IP address</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ICMP Header</strong> (8 bytes)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of message</td>
<td></td>
<td>Code</td>
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</tr>
<tr>
<td>Checksum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ICMP Payload</strong> (optional)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Header Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payload Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Exercise

• Ping yourself.  What is the ping time?
• Ping the router.  What is the ping time?
• Ping winnie (our baxter).  What is the ping time?
• Ping google.com
• Ping www.korea-dpr.com/.  Does it reply?  Is it up?
TCP (Transmission Control Protocol)

- Host-to-host connectivity.
- Ports!
- Open Socket, Close Socket, make it look like a file.
- What does it hide?
  - Lost packets
  - Duplicated packets
  - Out-of-order packets
- How does it leak?
  - Accurate delivery, not timely delivery.
  - Won’t work if you are disconnected.
Problems

- Connect two computers?
- Send data to another network?
- Dropped packets?
- Fast transmission?
- How do we use names instead of IP addresses?
- Obtaining an initial IP address?
- How do we share one IP address?
- How do we talk to the robot?
UDP (User Datagram Protocol)

- Host-to-host connectivity
- Ports
- Checksums
- Lost packets, duplicate packets, out-of-order packets might happen!
- What does it hide?
  - Checksums
- How does it leak?
  - Won’t work if disconnected.
Pipes

- cat file
- cat
- echo hello world | cat
Exercise

• Write cat in python. Read from standard input, write to standard output.

```python
#!/usr/bin/env python
import sys

while True:
    line = sys.stdin.readline()
    if line == "":
        break
    print(line[0:-1])
```
Netcat

- Netcat is cat over the interwebs.
- You can listen on a port and print out what the client says. Or you can connect to a port and type text that is sent to the server.
Exercise

• Use netcat to connect to google.com on port 80. Type random text. What happens? Why?

• Now use it to pretend to be a web browser. The most basic HTTP request is GET. Type “GET http://www.google.com/index.html”. What happens? Why?

• Now be a server. Run “nc -l 1234”. Point your web browser to this server. What does netcat print? Why?
Exercise

- Use netcat to connect to your computer. In one terminal, set up a server. In another terminal set up a client.

- Now use netcat to connect to a friend’s computer. Have one of you make a server; the other make a client. You made a basic chat client!!
Firewalls

• Rules about what traffic you
Exercise

• What does ping do? What protocol? How does it work?
DNS (Domain Name System)

- World-wide system for mapping IP addresses to names.
- I pay godaddy.com for the domain name, and pair.com to run a DNS server and host a public website.
- What does it hide?
  - IP addresses are ugly numbers.
- How does it leak?
  - The public internet has a complicated DNS system that you have to buy into. You often want DNS on your LAN but it won’t translate into the public internet. Also setting up a DNS on a LAN is work and many routers don’t do it by default.
DHCP (Dynamic Host Configuration Protocol)

- Connect to a new network.
- Ask the world for an IP address
  - Protocol: UDP
- What does it hide?
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  - You don’t have to configure other network settings, like the gateway or the broadcast mask.
- How does it leak?
  - If no DHCP server, no IP address.
Exercise

- Find a partner. Plug your computers directly together with Ethernet. Write a program that causes text on one person’s terminal to appear on the other person’s terminal.

- Now do it over wifi!
nmap

- Zmap: large-scale scanning, lots of parallelism and options to keep bandwidth minimal.
Exercise

- What ports are open on winnie? Why isn’t ros port 11311 shown in the results?
- What ports are open on google.com?
- Use nc to make a server on a random port, less than 1000. Don’t tell your partner what port.
- Use nmap to port scan your partner to figure out what port they are listening on.
Exercise

• Find the robots! What IP addresses on our LAN are associated with robots?
  - nmap 192.168.*.* -p11311
NAT (Network Address Translation)

- IP addresses are expensive!
  - My Comcast: $40/month
  - My T-Mobile bill: $57/month
- Lets you share one IP address with lots of people.
- What does it hide?
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- How does it leak?
  - You can’t be a server on the Internet from behind a NAT.
  - Port forwarding can be used to work around this.
Lab Router (and your home router)

- Routing (in the IP sense).
- NAT
- DHCP
- Firewall
- Wifi AP Master
- Ethernet Switch
Exercise

• What ports are open on the LAN side of the router?
• What ports are open on the WAN side of the router? (How can you find out without logging into the router?)
• What is the RLAB router? What ports are open there?
ROS (Robot Operating System)

- Application network protocol for
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- Convention for organization of software on the file system for compiling and running (dependency management).

- Library of useful robot software. (Transforms, filters, visualization, etc.).
ROS Master

- ROS Master is an XML RCP server. This is an HTTP server running XML RCP at the
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  – I can’t be a server. Had to do gymnastics to play Minecraft with my brother-in-law.
Open Questions

• The drone has a DHCP server but no Dynamic DNS set up. How do you set up dynamic DNS on the drone so you can ping by hostname as well as by IP address?

• What is the best way for 25 drones and base stations to run at the same time?

• What is the best way to give the drone internet access?
Software Engineering for Robotics

- Lots of different processes talk to each other.
- Processes live on different computers.
- Development trees live in different source control repository.
- Dependency management!
ROS (Robot Operating System)

- ROS is many things
  - Standard for message passing and RPC calls
  - Standard for organizing large repositories of code for different purposes. (Compiling, running, dependency management.)
  - Implementations of useful robotic libraries.
    - TF (Transform library)
    - Rviz (Visualization)
    - rosjs (Javascript/web page integration)
    - Many more!
ROS (Robot Operating System)

• ROS advantages
  – It is the current standard. Everyone uses it.
  – It provides a mechanism for most common robotics problems.

• ROS disadvantages
  – Very (overly) complicated.
  – Dependencies are still hard (but easier than before ROS).
  – Some poor design decisions related to message passing, etc.
Design Scenario

- Robot wants to send IR stream.

- state_controller.py – receives camera, IR, IMU and sends control commands

- How should state_controller.py get IR input?
  - Function call?
  - Message passing?
Problems

- Connect two computers?
- Send data to another network?
- Dropped packets?
- Fast transmission?
- How do we use names instead of IP addresses?
- Obtaining an initial IP address?
- How do we share one IP address?
- How do we talk to the robot?