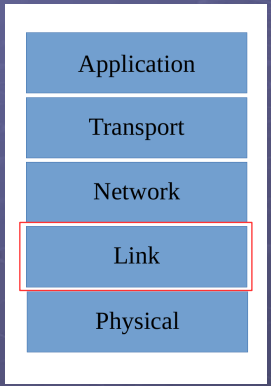
Systems and Devices 2 (Network)
Lec 5: Data Link Layer

Before we get started ...

- We have looked at how packets are transferred at the network layer i.e. host to host, using:
  - IP addresses across a WAN, a network or networks.
  - BUT, we have not considered how packets get from one host to another on a LAN e.g. how does a switch know which cable to transmit a packet down to get to a specific destination?
- Moving down to the Data link layer i.e. host to host communications on a LAN :
  - Physical addressing rather than logical addressing
  - Ethernet protocol, MAC addresses ...

Internet protocol stack



- Application
- Transport
- Network
- Link (layer 2)
  - Moves packets (**frames**) from one node (PC, router, switch etc) to another, error detection / correction. Different protocols depending on transmission medium used, we will focus on:
    - Ethernet protocol
  - Also, contains house keeping protocols to identify network addresses used.
    - Address Resolution Protocol (ARP)
- Physical

Ethernet Protocol

Name	Description	Status
IEEE 802.1	Higher Layer LAN Protocols Working Group	Active
IEEE 802.2	LLC	Disbanded
IEEE 802.3	Ethernet	Active
IEEE 802.4	Token bus	Disbanded
IEEE 802.5	Token Ring MAC layer	Disbanded
IEEE 802.6	MANs (DQDB)	Disbanded
IEEE 802.7	Broadband LAN using Coaxial Cable	Disbanded
IEEE 802.8	Fiber Optic TAG	Disbanded
IEEE 802.9	Integrated Services LAN (ISLAN or isoEthernet)	Disbanded
IEEE 802.10	Interoperable LAN Security	Disbanded
IEEE 802.11	Wireless LAN (WLAN) & Mesh (Wi-Fi certification)	Active
IEEE 802.12	100BaseVG	Disbanded
IEEE 802.13	Unused[2]	reserved for Fast Ethernet development[3]
IEEE 802.14	Cable modems	Disbanded
IEEE 802.15	Wireless PAN	Active

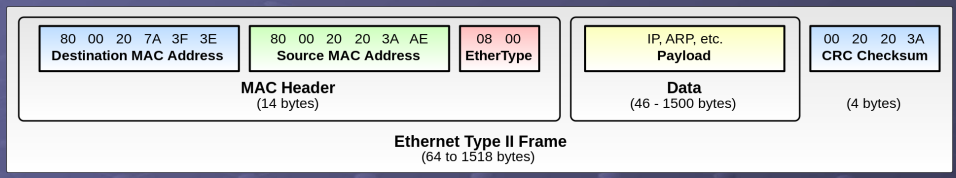
- Ethernet protocol
  - IEEE 802 family : https://en.wikipedia.org/wiki/IEEE_802

Ethernet Protocol

Ethernet standard	Date	Description
802.3a	1985	10BASE2 10 Mbit/s (1.25 MB/s) over thin Coax (a.k.a. thinnet or cheapernet)
802.3b	1985	10BROAD36
802.3c	1985	10 Mbit/s (1.25 MB/s) repeater specs
802.3-1985	1985	a revision of the base standard from 1983
802.3d	1987	Fiber-optic inter-repeater link
802.3e	1987	1BASE5 or StarLAN, first use of (voice-grade) twisted pair cabling, 1 Mbit/s, maximum reach of 250 to 500 m
802.3i	1990	10BASE-T 10 Mbit/s (1.25 MB/s) over twisted pair
802.3j	1993	10BASE-F 10 Mbit/s (1.25 MB/s) over optical fiber
802.3q	1993	GDMO (ISO 10164-4) format for Layer Managed Objects
802.3u	1995	100BASE-TX, 100BASE-T4, 100BASE-FX Fast Ethernet at 100 Mbit/s (12.5 MB/s) with autonegotiation
802.3x	1997	Full Duplex and flow control; also incorporates DIX framing, so there's no longer a DIX/802.3 split
802.3y	1998	100BASE-T2 100 Mbit/s (12.5 MB/s) over voice-grade twisted pair
802.3z	1998-07	1000BASE-X Gbit/s Ethernet over optical fiber at 1 Gbit/s (125 MB/s)
802.3-1998	1998-07	(802.3aa) A revision of base standard incorporating the above amendments and errata
802.3ab	1999-06	1000BASE-T Gbit/s Ethernet over twisted pair at 1 Gbit/s (125 MB/s)

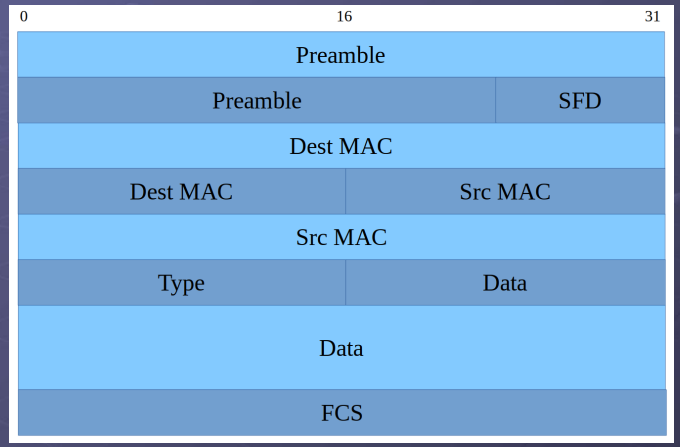
- Ethernet protocol
  - IEEE 802.3 family : https://en.wikipedia.org/wiki/IEEE_802.3

Ethernet Protocol



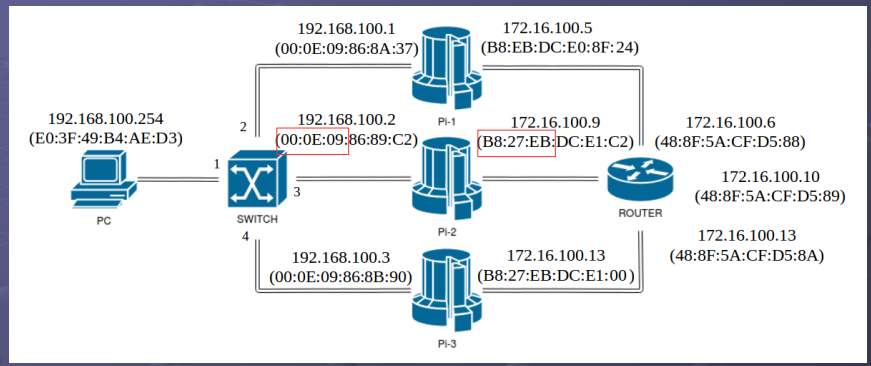
- Ethernet protocol
  - Create in 1983, no RFC rather an IEEE standard: 802.3
  - The default protocol used in LANs.
  - On a subnet hosts are identified using their Media Access Control (MAC) address, rather than their IP address.
    - A unique identifier, typically hard coded into each NIC at manufacture as a 48bit address, represented as six two-digit hexadecimal values.
  - Q : why are there min / max frame sizes?

Ethernet Protocol



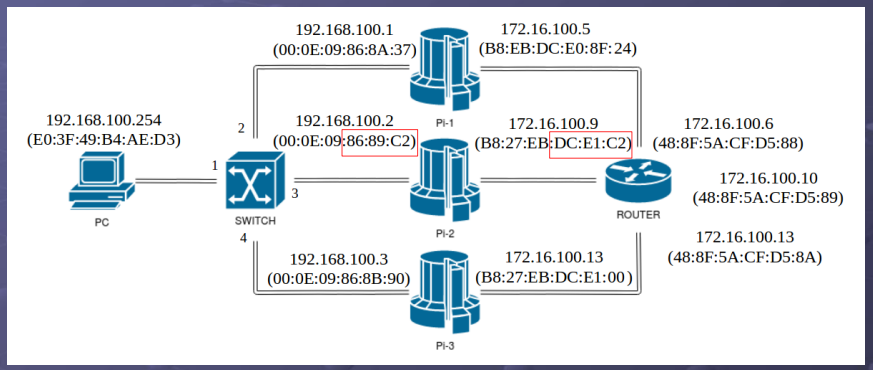
- Ethernet frame : 7 + 1 + 6 + 6 + 2 + 4 = 26B

Ethernet Protocol



- MAC addresses, two parts
  - Organisationally Unique Identifier (OUI)
  - Network Interface Controller Specific (NIC)

Ethernet Protocol

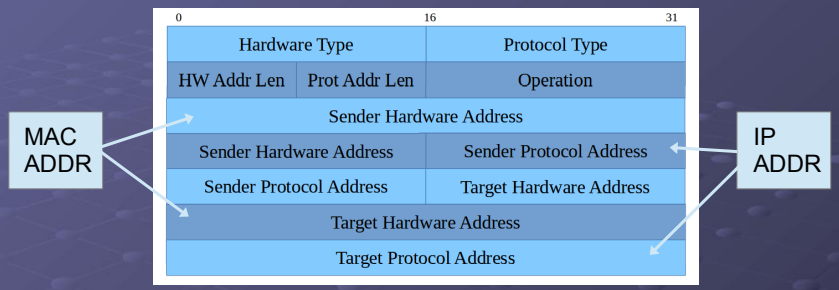


- MAC addresses, two parts
  - Organisationally Unique Identifier (OUI)
  - Network Interface Controller Specific (NIC)

Ethernet Protocol

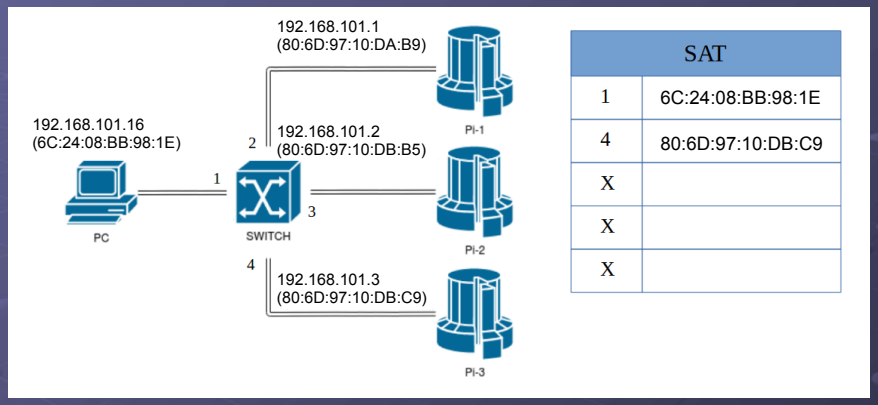
- Key points to remember:
  - Unlike a router, switches know nothing about IP addresses, they only “see” layer 2 protocols i.e. on a router each port is assigned an IP address, on a switch they are not.
  - Communication between ports is based on MAC addresses i.e. switch learns what host (MAC address) is connected to each port.
- Q: how does a host discover what MAC address is used by another host?

ARP



- Address Resolution Protocol
  - RFC 826 : https://datatracker.ietf.org/doc/html/rfc826
  - Defined in 1982, used by a number of early protocols e.g. when using IP this protocol allow a host to convert a logical address (IP) into a physical address (MAC).
  - Uses the broadcast MAC address FF:FF:FF:FF:FF:FF.

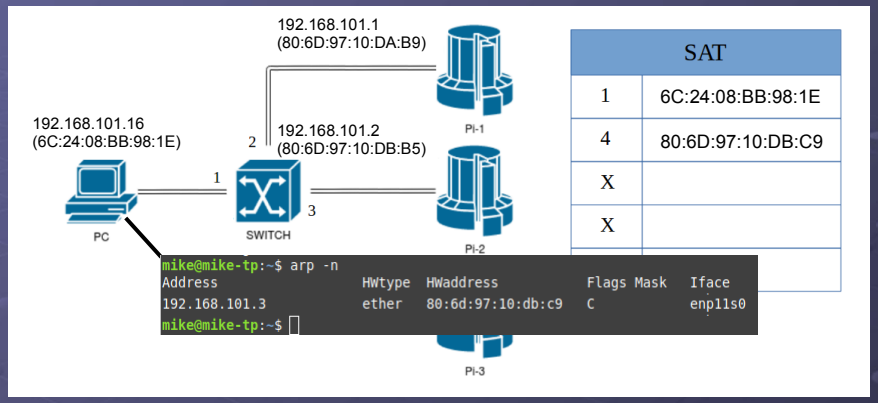
Example



SAT	
1	6C:24:08:BB:98:1E
4	80:6D:97:10:DB:C9
X	
X	
X	

- Source Address Table (SAT)
  - Mapping port number to MAC address. In this example PC and Pi-3 have communicated previously (ports 1 & 4)

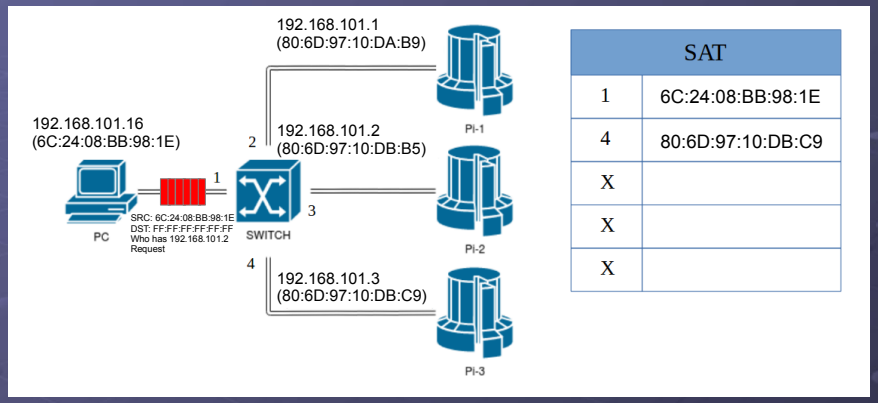
Example



SAT	
1	6C:24:08:BB:98:1E
4	80:6D:97:10:DB:C9
X	
X	

- PC wants to communicate with Pi-2
  - PC wants to communicate with Pi-2, it checks for Pi-2's IP address in its ARP table, MISS :(

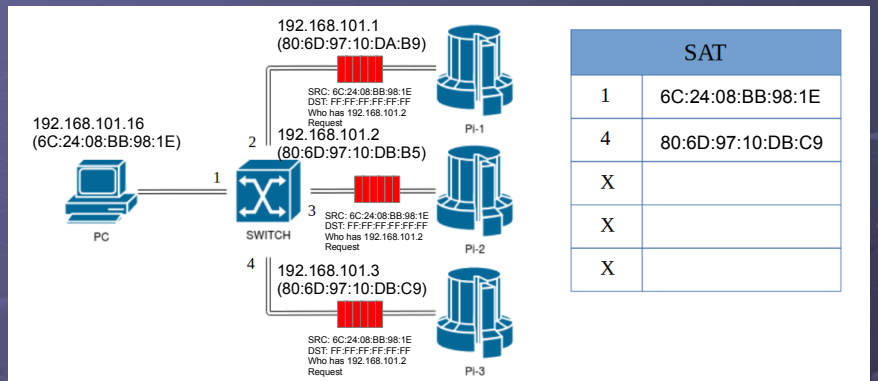
Example



SAT	
1	6C:24:08:BB:98:1E
4	80:6D:97:10:DB:C9
X	
X	
X	

- PC wants to communicate with Pi-2
  - PC knows IP address, doesn't know MAC address. Broadcasts a "Who has"

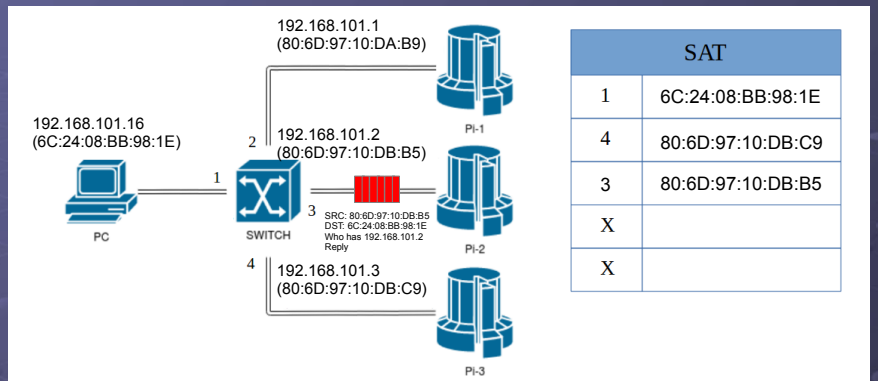
Example



SAT	
1	6C:24:08:BB:98:1E
4	80:6D:97:10:DB:C9
X	
X	
X	

- Broadcast received by switch, no matching MAC in SAT, switch re-broadcast on other ports (not src).

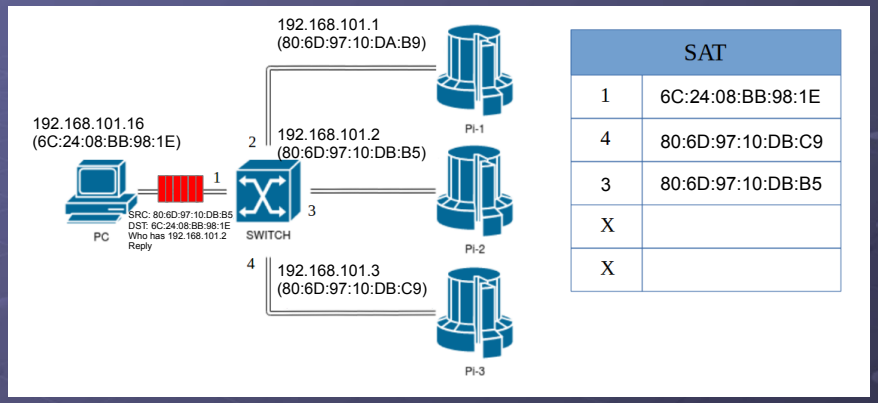
Example



SAT	
1	6C:24:08:BB:98:1E
4	80:6D:97:10:DB:C9
3	80:6D:97:10:DB:B5
X	
X	

- Pi-2 matches requested IP address, transmits back an ARP response packet via switch.

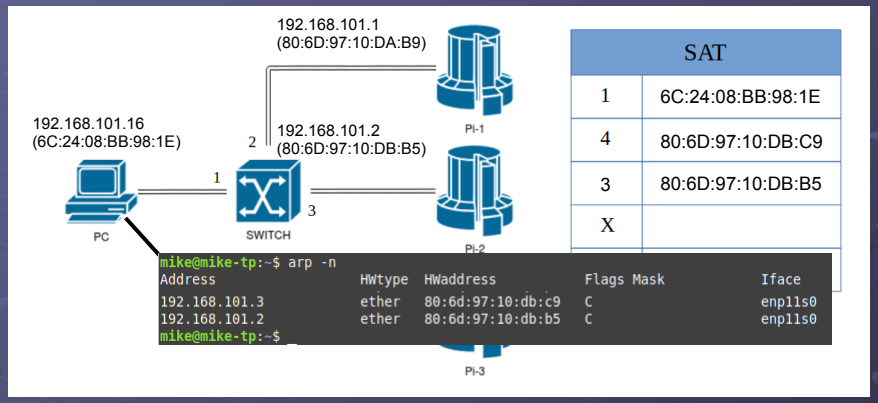
Example



SAT	
1	6C:24:08:BB:98:1E
4	80:6D:97:10:DB:C9
3	80:6D:97:10:DB:B5
X	
X	

- Destination MAC matched in SAT, packet forwarded to port 1.

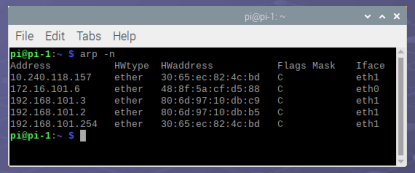
Example

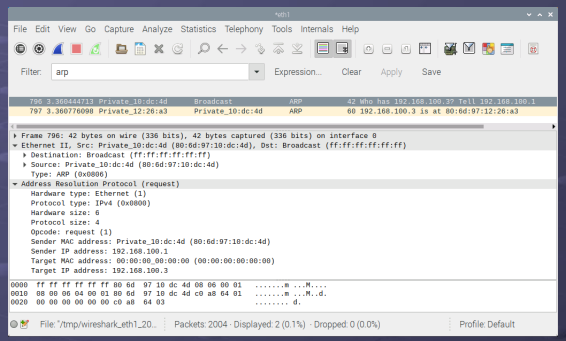


SAT	
1	6C:24:08:BB:98:1E
4	80:6D:97:10:DB:C9
3	80:6D:97:10:DB:B5
X	

- PC wants to communicate with Pi-2 again
  - Checks for Pi-2's IP address in its ARP table, HIT, use MAC address from table.

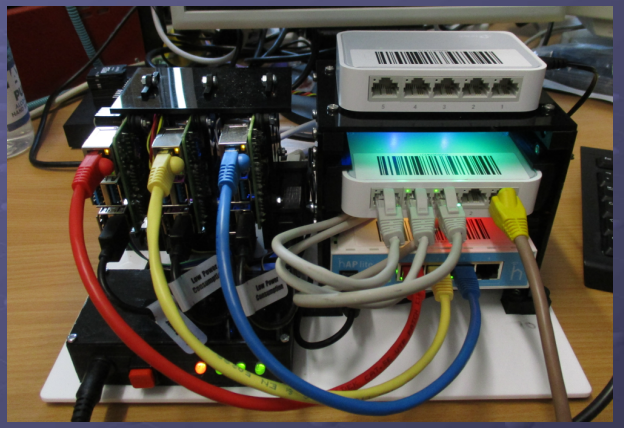
Demo





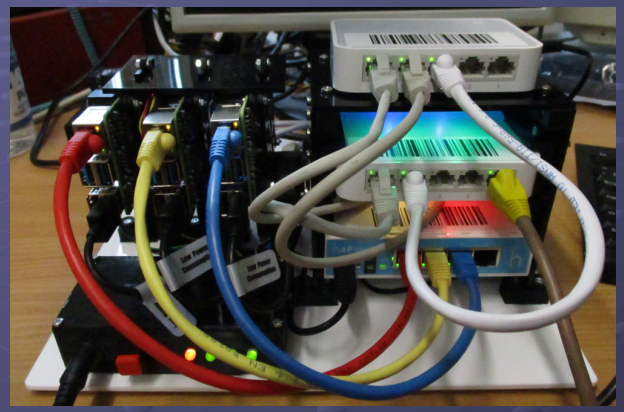
- Triggering ARP request and response packets
  - `arp -n`
  - `arp -d <IP>`
  - `ping <IP>`

Quick Quizzz



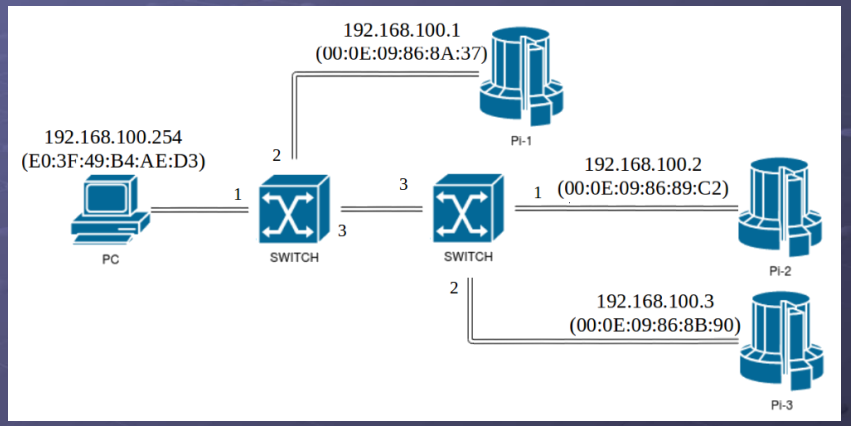
- To test out these ideas consider what will happen to the Raspberry Pi system if we add a second switch

Quick Quizzz



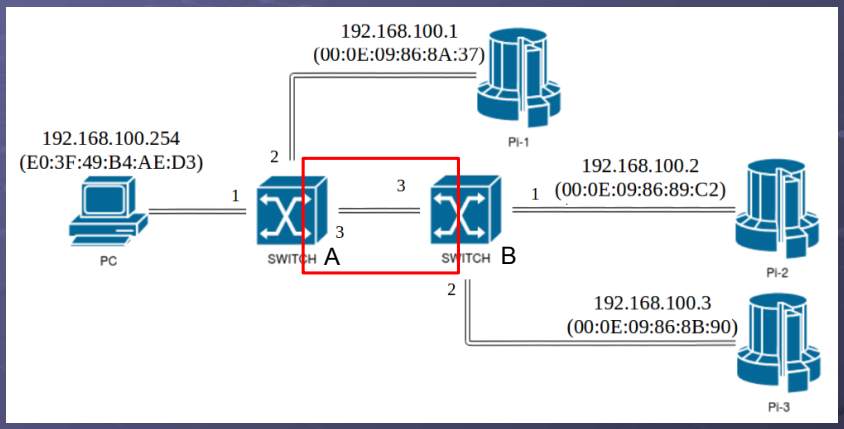
- Move eth1 from Pi-2 and Pi-3 onto second switch + one patch cable between switches.

Quick Quizzz



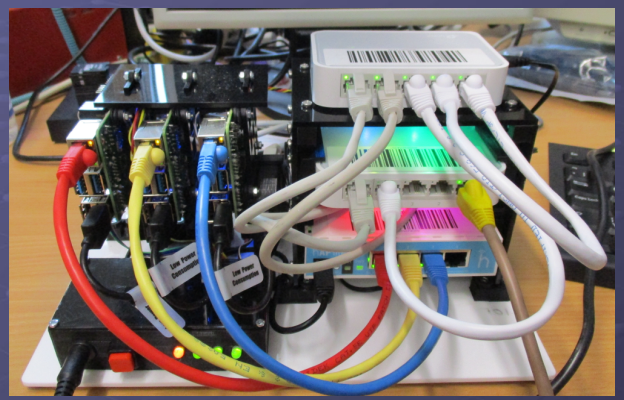
- Q : will this network still work?

Quick Quizzz



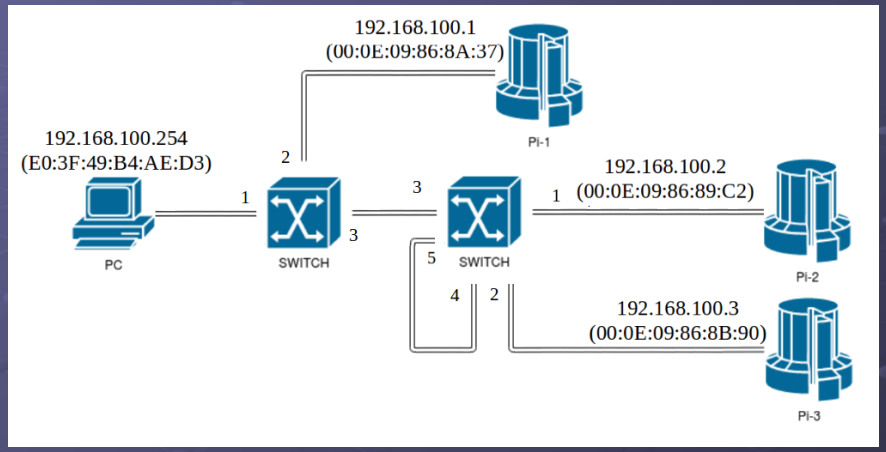
- Q : What will the SAT look like in the two switches (A & B) for port 3 i.e. SWA-p3 and SWB-p3?

Quick Quizzz



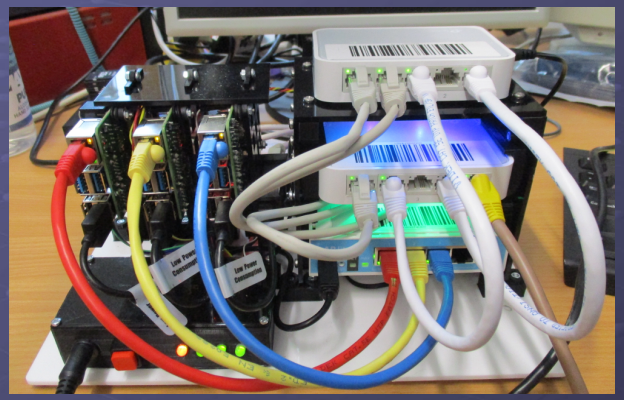
- Move eth1 from Pi-2 and Pi-3 onto second switch + one patch cable between switches + a link between ports.

Quick Quizzz



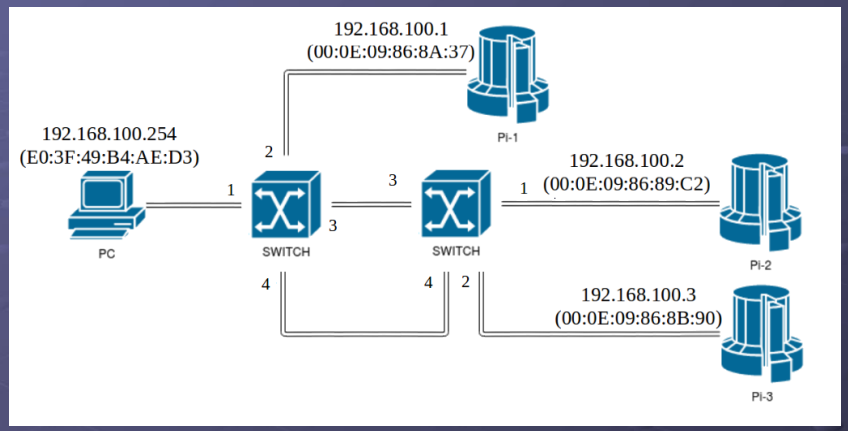
- Q : will this network still work?

Quick Quizzz



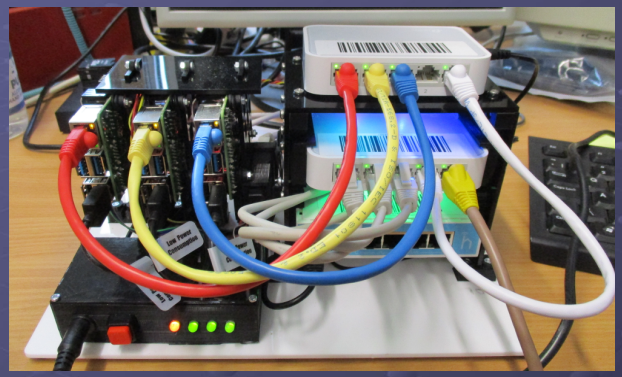
- Move eth1 from Pi-2 and Pi-3 onto second switch + two patch cables between switches.

Quick Quizzz



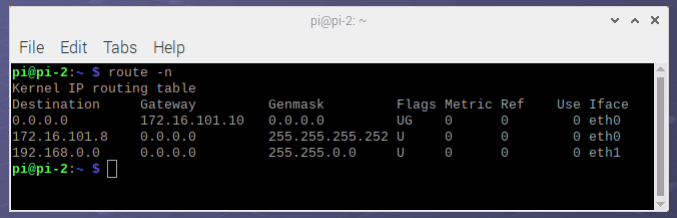
- Q : will this network still work?
  - Note, cheap dumb switches no link aggregation allowed :)

Quick Quizzz



- Move eth0 from Pi-1, Pi-2 and Pi-3 onto second switch + patch cable between switches
- Q : will the network still work?

Quick Quizzz



- A : no, but perhaps not because of the reason you are thinking of.
- Q : what changes do you need to make to this system to allow it to work correctly?
  - What routes do you need to delete?
  - What routes do you need to add?

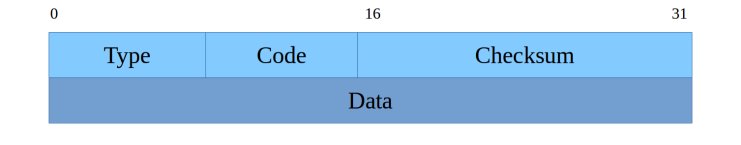
Some questions to consider ...

```
pi@pi-1:~ $ ping 10.100.2.2
PING 10.100.2.2 (10.100.2.2) 56(84) bytes of data.
From 172.16.100.6 icmp_seq=1 Destination Net Unreachable
From 172.16.100.6 icmp_seq=2 Destination Net Unreachable
^C
--- 10.100.2.2 ping statistics ---
2 packets transmitted, 0 received, +2 errors, 100% packet loss, time 2ms

pi@pi-1:~ $
```

- Q : what protocol does the Ping command use?
  - How does Ping know that the destination network is unreachable?
- Q : how are errors signalled on a network?
  - Destination network, host, protocol, port is unreachable, TTL count expires etc.
- Q : do we need another protocol?

ICMP



- Internet Control Message Protocol
  - RFC792 : https://datatracker.ietf.org/doc/html/rfc792
  - Defined in 1981, like UDP designed to be a very light weight protocol.
  - ICMP uses the IP protocol to transport its data, however, unlike TCP/UDP it is not used to transfer “user” data (segments). Therefore, as this protocol was designed alongside IP it is considered a layer 3 protocol (network layer), could argue layer 4, but it feels like a layer 3.5 :).

ICMP

Type	Code	Status	Description
0 – Echo Reply[6]:14	0		Echo reply (used to ping)
1 and 2		unassigned	*Reserved*
3 – Destination Unreachable[6]:4	0		Destination network unreachable
	1		Destination host unreachable
	2		Destination protocol unreachable
	3		Destination port unreachable
	4		Fragmentation required, and DF flag set
	5		Source route failed
	6		Destination network unknown
	7		Destination host unknown
	8		Source host isolated
	9		Network administratively prohibited
	10		Host administratively prohibited
	11		Network unreachable for ToS
	12		Host unreachable for ToS
	13		Communication administratively prohibited
	14		Host Precedence Violation
	15		Precedence cutoff in effect

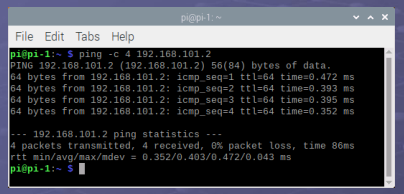
- ICMP types and codes

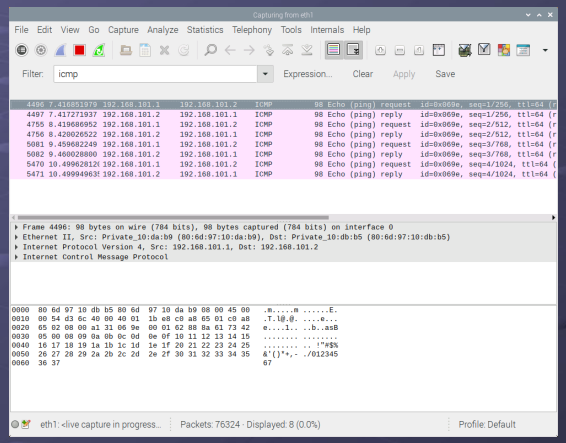
ICMP

Type	Code	Status	Description
4 – Source Quench	0	deprecated	Source quench (congestion control)
5 – Redirect Message	0		Redirect Datagram for the Network
	1		Redirect Datagram for the Host
	2		Redirect Datagram for the ToS & network
	3		Redirect Datagram for the ToS & host
6		deprecated	Alternate Host Address
7		unassigned	*Reserved*
8 – Echo Request	0		Echo request (used to ping)
9 – Router Advertisement	0		Router Advertisement
10 – Router Solicitation	0		Router discovery/selection/solicitation
11 – Time Exceeded[6]:6	0		TTL expired in transit
	1		Fragment reassembly time exceeded
12 – Parameter Problem: Bad IP header	0		Pointer indicates the error
	1		Missing a required option
	2		Bad length
13 – Timestamp	0		Timestamp
14 – Timestamp Reply	0		Timestamp reply
15 – Information Request	0	deprecated	Information Request
16 – Information Reply	0	deprecated	Information Reply

- ICMP types and codes

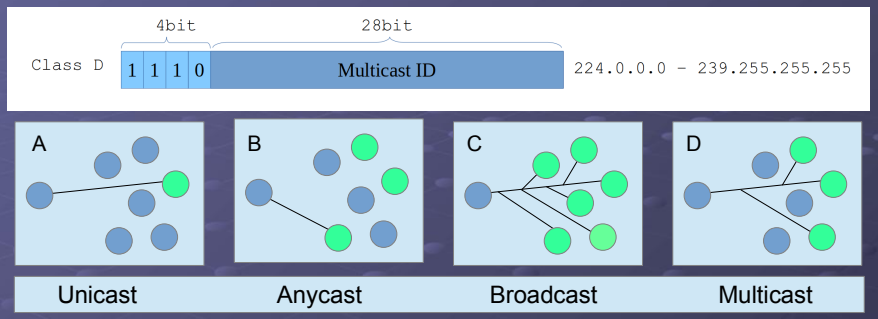
Demo





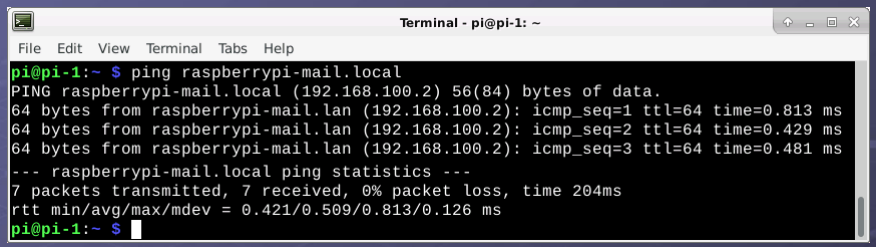
- ICMP ping packets
- More than just PING e.g. try running your `udpTX.py` without `udpRX.py` ICMP will tell the TX host to stop.

Multicast



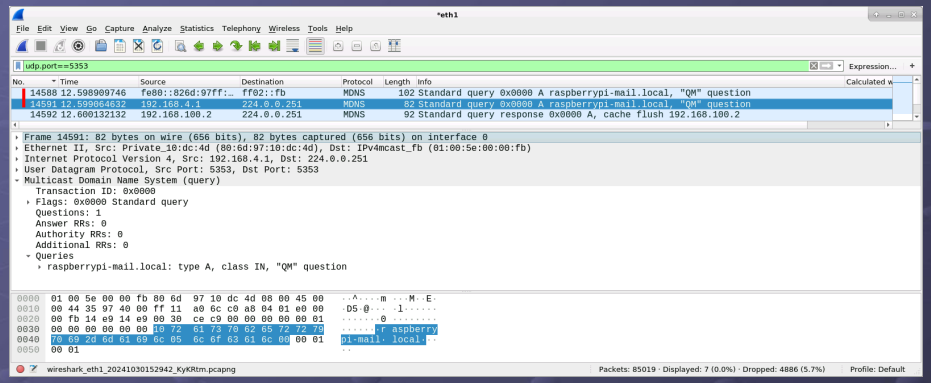
- What happens in layer 2 when we use multicast?
- Transfers are now not to a single destination MAC?
  - We need one-to-many communications.
- Note, multicast address blocks allocated to specific functions e.g. local multicast : 224.0.0.0 to 224.0.0.255

Multicast



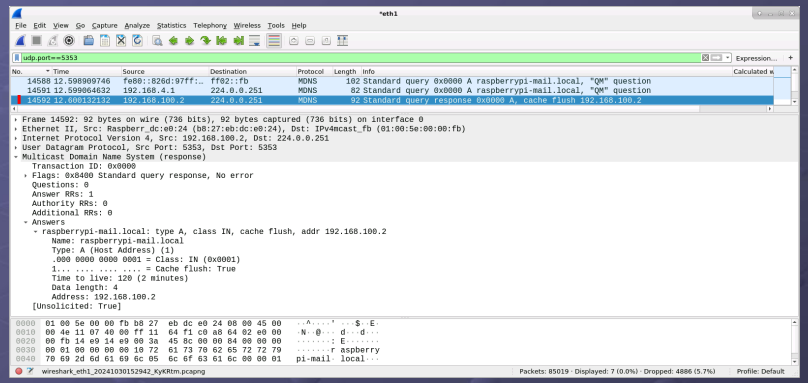
- Easy way of generating “multicast” packets is mDNS
  - Multicast Domain Name System (mDNS)
  - RFC 6762 : https://datatracker.ietf.org/doc/html/rfc6762
  - Configuration free, resolves hostnames to IP addresses in small networks, common implementations : Bonjour & Avahi
    - `.local` is the local area network (local link)
  - IP address : IPv4 – 224.0.0.251 and IPv6 – ff02::fb
  - Port : 5353

Multicast



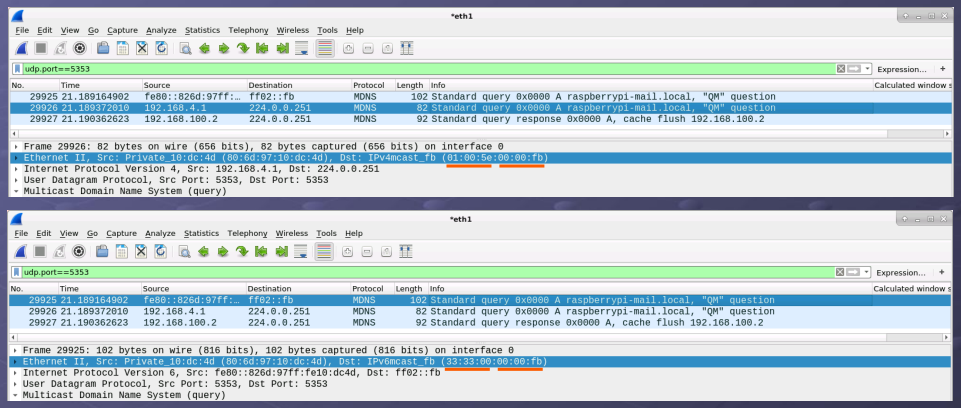
- To resolve `.local` names Pi-1 puts two multicast packets onto the network i.e. an IPv4 and IPv6 multicast DNS query.

Multicast



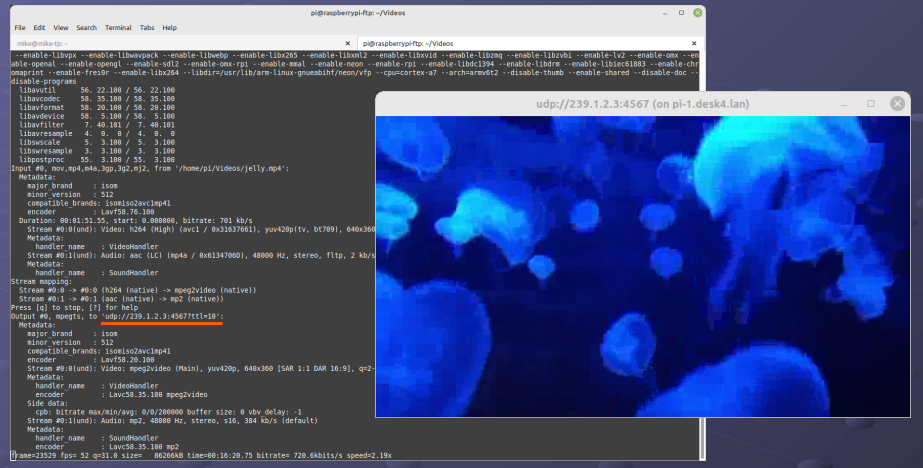
- The Raspberry Pi mail server matches the query to its host name and responds with its IP address.
  - Q : why would pinging pi-1.local cause issues?

Multicast



- To implement one-to-many connections the Ethernet protocol defines multicast MAC addresses for IPv4 and IPv6.

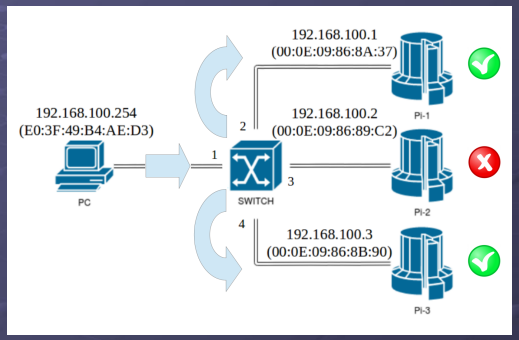
Example : video streams



- Example : in the lab, a stream of jellyfish :)

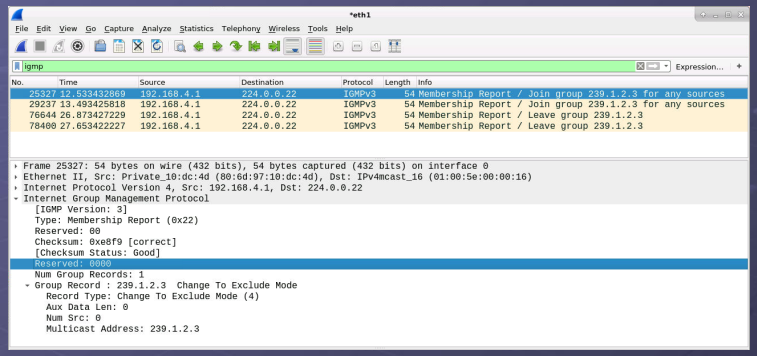
Multicast

- When using multicast we only want packets to go to hosts that want them
  - Not a broadcast.
- Clients wanting to RX multicast packets will listen on the multicast MAC address.
  - Do not TX on this MAC



- Therefore, what will the switch do? What is a switch's default behaviour when it can not find a MAC address in its SAT?

Multicast



- Internet Group Management Protocol (IGMP)
  - Membership reports : join and leave messages
  - RFC 2236 : https://datatracker.ietf.org/doc/html/rfc2236
  - Need a switch that supports IGMP snooping :(

Summary

- We have now finished looking at network protocols
  - There are lot more protocols to look at and the ones we have looked at we have only scratched the surface e.g. DNS, TCP, IPv6, routing protocols ...
  - BUT you should now have a basic understanding of the Internet protocol stack and the different protocols commonly used.
- However, we still have some unanswered questions:
  - What cables do these signals travel across, what do the electrical signals look like ...
  - Are all Ethernet cables the same?