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

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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 ...

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Internet protocol stack

- Application
- Transport
- Network
- Link (layer 2)
- Network

Application

Transport

- Link
- Physical

- 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 University of York : M Freeman 2024

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
<u>′</u>	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
\sim	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 University of York : M Freeman 2024

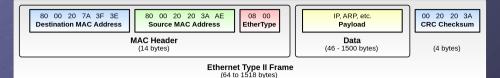
Ethernet Protocol

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 University of York : M Freeman 2024

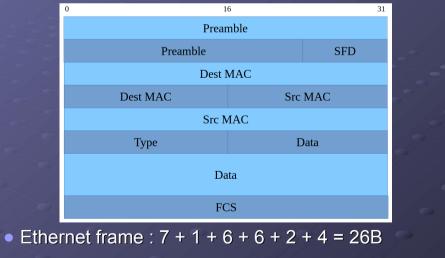
Ethernet Protocol



Ethernet protocol

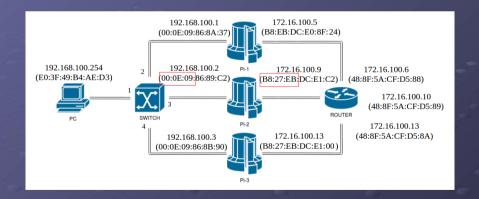
- Create in 1983, no RFC rather an IEEE standard: 802.3
- The default protocol used in LANs.
- On a subnet hosts are identified using their Media Access Control (MAC) address, rather than their IP address.
 - A unique identifier, typically hard coded into each NIC at manufacture as a 48bit address, represented as six two-digit hexadecimal values.
- Q : why are there min / max frame sizes? University of York : M Freeman 2024

Ethernet Protocol



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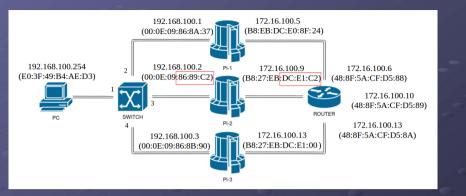
Ethernet Protocol



• 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)

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Ethernet Protocol

Switch port

• Key points to remember:

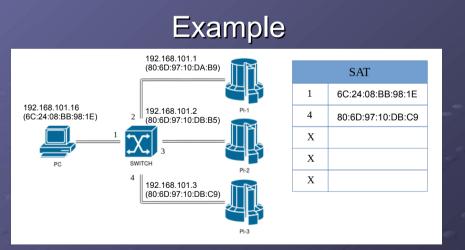
- Unlike a router, switches know nothing about IP addresses. they only "see" layer 2 protocols i.e. on a router each port is assigned an IP address, on a switch they are not.
- Communication between ports is based on MAC addresses i.e. switch learns what host (MAC address) is connected to each port.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

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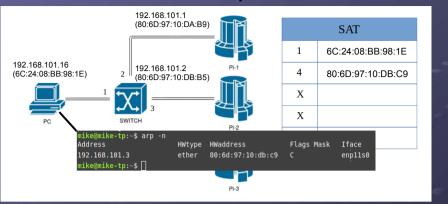
Address Resolution Protocol

- 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. University of York : M Freeman 2024



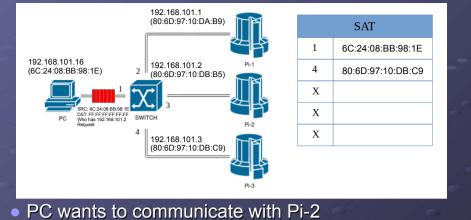
- Source Address Table (SAT)
 - Mapping port number to MAC address. In this example PC and Pi-3 have communicated previously (ports 1 & 4) University of York : M Freeman 2024

Example

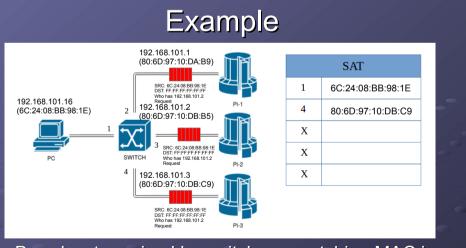


- PC wants to communicate with Pi-2
 - PC wants to communicate with Pi-2, it checks for Pi-2's IP address in its ARP table, MISS :(University of York : M Freeman 2024

Example

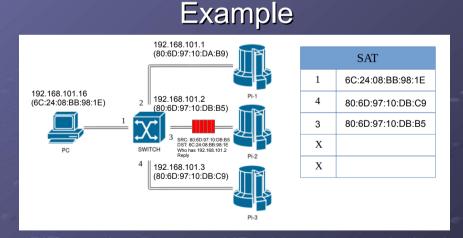


 PC knows IP address, doesn't know MAC address. Broadcasts a "Who has" University of York : M Freeman 2024



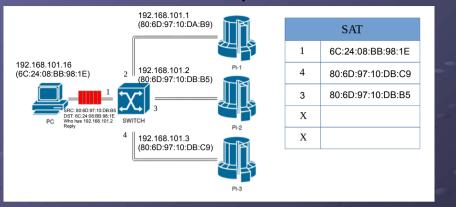
 Broadcast received by switch, no matching MAC in SAT, switch re-broadcast on other ports (not src).

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

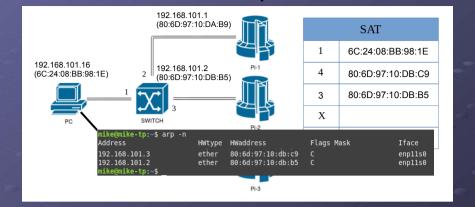
Example



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

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Example



• 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. University of York : M Freeman 2024

Demo e Edit Tabs Help 🔐 🕅 💽 🚍 · Evoression Clear 42 Who has 192.168.100.37 Tell 192.168 60 192.168.100.3 is at 80:6d:97:12:26: ytes on wire (336 bits), 42 bytes captured (336 bits) on interface 8 c: Private_10:dc:4d (80:6d:97:10:dc:4d), Dst: Broadcast (ff:ff:ff:ff: Broadcast (ff:ff:ff:ff:ff:ff:ff:ff: rce: Private 10:dc:4d (80:6d:97:10:dc:4d) Triggering ARP ware size: ocol size: 4 request and request (1) MAC address: Private_10:dc:4d (80:6d:97:18:dc:4d) IP address: 192.168.100.1 MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00) IP address: 192,168,100.3 response packets ff ff ff ff ff ff ff 80 6d 97 10 dc 4d 08 06 00 01 88 09 06 04 00 01 80 6d 97 10 dc 4d c0 a8 64 01 00 00 00 00 00 00 00 c0 a8 64 03 File: "/tmp/wireshark eth1 20... Packets: 2004 · Displayed: 2 (0.1%) · Dropped: 0 (0.0%) Profile: Default ▶ arp -n ▶ arp -d <IP> ▶ ping <IP> University of York : M Freeman 2024

Quick Quizzz



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

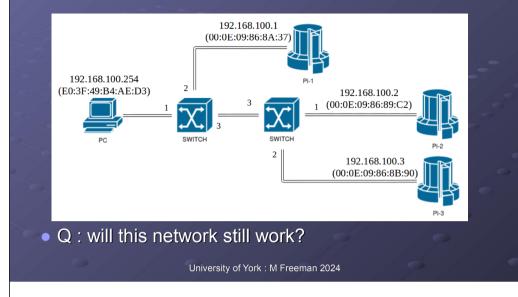
Quick Quizzz



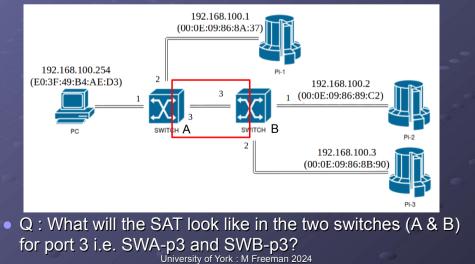
 Move eth1 from Pi-2 and Pi-3 onto second switch + one patch cable between switches.

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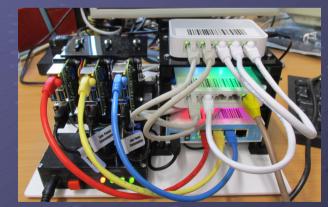
Quick Quizzz



Quick Quizzz

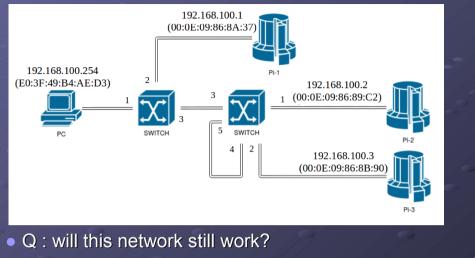


Quick Quizzz



 Move eth1 from Pi-2 and Pi-3 onto second switch + one patch cable between switches + a link between ports. University of York : M Freeman 2024

Quick Quizzz



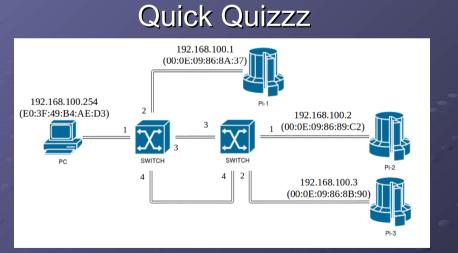
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Quick Quizzz



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

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- Q : will this network still work?
 - Note, cheap dumb switches no link aggregation allowed :) University of York : M Freeman 2024

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

File Edit Tak	os Help					
ji@pi-2:~ \$ ro (ernel IP rout)estination	ing table	Connach	51	Maturia	Def	 7.6
	Gateway 172.16.101.10	Genmask 0.0.0.0	F Lags UG	Metric 0	кет 0	Iface eth0
72.16.101.8	0.0.0.0	255.255.255.252				eth0
192.168.0.0 Di@pi-2:~ \$ []	0.0.0.0	255.255.0.0				eth1

- 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?

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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?

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ICMP

	IC	CMP	
0		16	31
Туре	Code	Checksum	
		Data	

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 :). University of York : M Freeman 2024

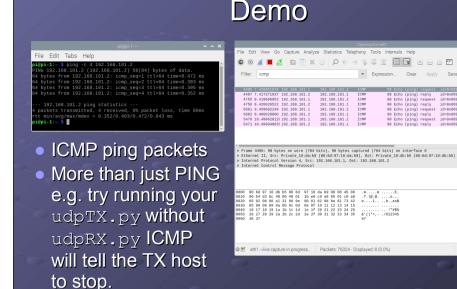
Туре	Code	Status	Description
0 - Echo Reply ^{[6]:14}	0		Echo reply (used to ping)
1 and 2		unassigned	Reserved
	0		Destination network unreachable
	1		Destination host unreachable
	2		Destination protocol unreachable
	3		Destination port unreachable
	4		Fragmentation required, and DF flag set
	5		Source route failed
	6		Destination network unknown
3 - Destination Unreachable ^{[6]:4}	7		Destination host unknown
3 - Destination Unreachable(4).4	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
CMP types ar			

ICMP

Туре	Code	Status	Description
4 - Source Quench	0	deprecated	Source quench (congestion control)
	0		Redirect Datagram for the Network
5 - Redirect Message	1		Redirect Datagram for the Host
5 – Redirect Message	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
11 - Time Exceeded(s)(s	1		Fragment reassembly time exceeded
	0		Pointer indicates the error
12 - Parameter Problem: Bad IP header	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

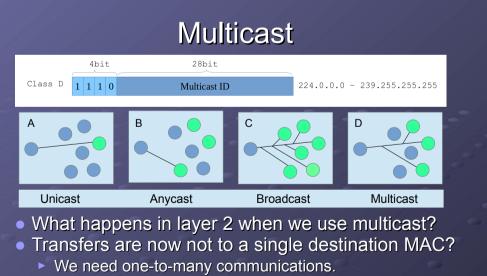
ICMP types and codes

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Profile: Defaul

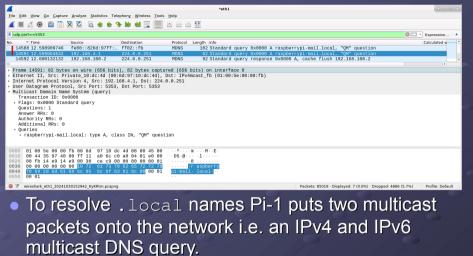


 Note, multicast address blocks allocated to specific functions e.g. local multicast : 224.0.0.0 to 224.0.0.255 University of York : M Freeman 2024

	Multicast	
	Terminal - pi@pi-1: ~	(+ _ = ×
File Edit View Terminal Tabs	Help	
64 bytes from raspberryp 64 bytes from raspberryp 64 bytes from raspberryp 64 caspberrypi-mail.loc 7 packets transmitted, 7	cal (192.168.100.2) 56(84) bytes of data. i-mail.lan (192.168.100.2): icmp_seq=1 ttl=64 i-mail.lan (192.168.100.2): icmp_seq=2 ttl=64 i-mail.lan (192.168.100.2): icmp_seq=3 ttl=64 i-mail.lan (192.168.100.2): ic	time=0.429 ms

- 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



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Multicast

4		"eth1			0 - 6 2
Ele Edit View Go Capture Analyze Statistics Teleph	hony Wireless Tools Help				
🛋 🔳 🖉 💿 🕋 🗋 🗙 🚱 🙇 💩 🏵	16 el 🗉 🔲 o o /	a 🚺			
udp.port==5353					Expression
		Length Info			Calculated w
14588 12.598909746 fe80::826d:97ff: f			0x0000 A raspberrypi-mail.loc		
	224.0.0.251 MDNS 224.0.0.251 MDNS		/ 0x0000 A raspberrypi-mail.loc / response 0x0000 A, cache flus		
14592 12.000132132 192.100.100.2 2	24.0.0.251 MUNS	92 Scandard query	r response oxoobo A, cache rius	1 192.100.100.2	
Frame 14592: 92 bytes on wire (736 bits).	02 butos contured (72)	hite) on interface 0			
Ethernet II, Src: Raspberr_dc:e8:24 (b8:2			e:ee:fb)		
Internet Protocol Version 4, Src: 192.168			0.00.10)		
 User Datagram Protocol, Src Port: 5353, D 		-			
- Multicast Domain Name System (response)					
Transaction ID: 0x0000					
 Flags: 0x8400 Standard query response, 	No error				
Questions: 0					
Answer RRs: 1					
Authority RRs: 0					
Additional RRs: 0					
 Answers raspberrypi-mail.local: type A. class 	- West				
 raspberrypi-mail.local: type A, class Name: raspberrypi-mail.local 	s in, cache fiush, addr	192.168.100.2			
Type: A (Host Address) (1)					
.000 0000 0000 0001 = Class: IN (0)	148081)				
1 = Cache flush:					
Time to live: 120 (2 minutes)					
Data length: 4					
Address: 192,168,100,2					
[Unsolicited: True]					
0000 01 00 5e 00 00 fb b8 27 eb dc e0 2		·' ···\$··E·			
0010 00 4e 11 07 40 00 ff 11 64 f1 c0 a		··· d···· d· ···			
0020 00 fb 14 e9 14 e9 00 3a 45 8c 00 0 0030 00 01 00 00 00 00 10 72 61 73 70 0	62 65 72 72 70	-r aspberry			
6648 78 69 2d 6d 61 69 6c 85 6c 6f 63 6	61 6c 88 88 81 ni-ma	1 local			
	or co co co or pr-ma.				
Wireshark_eth1_20241030152942_KyKRtm.pcapng			Packets: 85019	Displayed: 7 (0.0%) · Dropped: 4886	(5.7%) Profile: Default

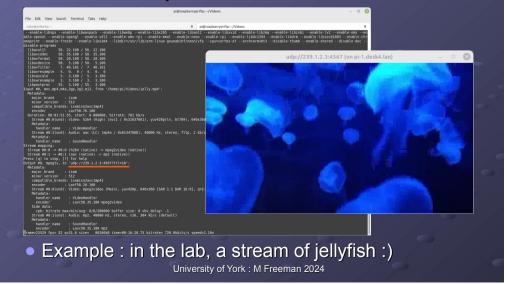
 The Raspberry Pi mail server matches the query to its host name and responds with its IP address.
 Q : why would pinging pi-1.local cause issues?

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Multicast Go Capture Analyze Statistics Telephony 🐵 🖆 🖺 🎗 🖏 💩 🔹 👁 🕍 🧮 🗏 0 o 0 🎹 Expression. Protocol Length Info MDNS 102 Standard guery 0x0000 A raspberrypi-mail.local, "OM" guestion 29925 21.189164902 fe80::826d:97ff;... ff02::fb 92 Standard query response Av8A0A A cache flush 192 168 100 82 bytes on wire (656 bits), 82 bytes captured Internet Try Sic, Private 10, doi:10.100/10/10/10/10/10 Internet Protocol Version 4, Src: 192.168.4.1, Dst: 22 Jser Datagram Protocol, Src Port: 5353, Dst Port: 535 (ulticast Domain Name System (guery) I 🗙 🙆 🔝 🌰 0 1 82 Standard query 0x0000 A raspberrypi-mail.local, "QM" questi 92 Standard query response 0x0000 A, cache flush 192.168.100.2 29926 21.189372010 192.168.4.1 29927 21.190362623 192.168.100.2 224.0.0.251 224.0.0.251 Frame 29925: 102 bytes on wire (816 bits), 102 bytes captured (816 bits) on interface 6 Internet Protocol Version 6, Src: fe80::826d:97ff:fe10:dc4d, Dst: ff02:: User Datagram Protocol, Src Port: 5353, Dst Port: 5353 Multicast Domain Name System (ouerv) To implement one-to-many connections the Ethernet protocol defines multicast MAC addresses for IPv4 and IPv6.

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Example : video streams



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
- 192.168.100.254 (E0:3F:49:B4:AE:D3) PC PC (0:0E:09:86:89:C2) (0:0E:09:86:89:C2) (0:0E:09:86:89:C2) (0:0E:09:86:89:C2) (0:0E:09:86:89:C2) (0:0E:09:86:88:90) (0:0E:09:86:88:80) (0:0E:09:86:88:80) (0:0E:09:86:80) (0:0E:09:86:80) (0:0E:09:86:80) (0:0E:09:80) (0:0E:09:80) (0:0E:09:80) (0:0E:09:80) (0:0E:09:80) (0:0E:09:80) (0:0E:09:80) (0:0E:09:80) (0:0E:09:
- Therefore, what will the switch do? What is a switch's default behaviour when it can not find a MAC address in its SAT?

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	Edit View Go Captur	e Analyze Statistics	Telephony Wireless Tool:	*eth1 s Help	
	i 🖉 💿 🛅 🛅	🗙 🙆 🙇 🎄 🛙	e 🤉 lie el 🗔 🗐		1 1
📕 igm	ıp				Expression
No.	Time	Source	Destination	Protocol	Length Info
25	5327 12.533432869	192.168.4.1	224.0.0.22	IGMPv3	54 Membership Report / Join group 239.1.2.3 for any sources
29	9237 13.493425818	192.168.4.1	224.0.0.22	IGMPv3	54 Membership Report / Join group 239.1.2.3 for any sources
76	6644 26.873427229	192.168.4.1	224.0.0.22	IGMPv3	54 Membership Report / Leave group 239.1.2.3
78	8400 27,653422227	192.168.4.1	224.0.0.22	IGMPv3	54 Membership Report / Leave group 239,1,2,3
• Int • Int	ternet Protocol V ternet Group Mana [IGMP Version: 3] Type: Membership Reserved: 00	ersion 4, Src: 1 gement Protocol Report (0x22)	(80:6d:97:10:dc:4d), 92.168.4.1, Dst: 224		mcast_16 (01:00:5e:00:00:16)
	Checksum: 0xe8f9				
	[Checksum Status: Reserved: 0000	6000 J			
	Num Group Records		To Exclude Mode		

- 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 :(

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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?