Wireless Standards & Protocols

Network Startup Resource Center
www.nsrc.org

Original Slides: Sebastian Büttrich, NSRC/ITU/wire.less.dk Edit: June 2012

Objectives

- Introduce Core Concepts & Terminology
  - Shared Radio Spectrum Bands
  - Wi-Fi & 802.11 radio channels
  - Channel Access
  - Wireless network topologies
  - Wi-Fi modes of operation
  - Basic wireless routing

What is Shared Spectrum?

- Licenses give an exclusive right to use a frequency
  - Radio & TV Stations, Cellular Operators
- Wi-Fi typically operates in shared spectrum
  - Many networks on the same frequencies
- Use of shared spectrum is free in most countries
- Free does not always mean unregulated or unlicensed
  - “Type Approved Devices”
  - Maximum Power Limits & Radar Detect
  - General User Radio Licenses

Is Shared Spectrum Important?

- Innovation happens in shared spectrum
- The market size is greater
- No country-specific frequencies to develop for
- Wi-Fi is often faster than cellular
- Wi-Fi is usually cheaper than cellular

Industrial, Scientific, Medical (ISM) Bands

- Spectrum originally set aside for ISM equipment
- Opened for use in the US in the 1990s
- Wi-Fi works in 2.4 GHz and 5.8 GHz ISM spectrum
- ISM bands also exist at:
  - 433 MHz
  - 915 MHz
  - 24 Ghz

ISM bands

Frequency range		Bandwidth	Center frequency	Availability
6.765 MHz	6.795 MHz	30 kHz	6.780 MHz	Subject to local acceptance
13.553 MHz	13.567 MHz	14 kHz	13.560 MHz	Worldwide
26.957 MHz	27.283 MHz	326 kHz	27.120 MHz	Worldwide
40.660 MHz	40.700 MHz	40 kHz	40.680 MHz	Worldwide
433.050 MHz	434.790 MHz	1.74 MHz	433.920 MHz	Region 1 only and subject to local acceptance
902.000 MHz	928.000 MHz	26 MHz	915.000 MHz	Region 2 only (with some exceptions)
2.400 GHz	2.500 GHz	100 MHz	2.450 GHz	Worldwide
5.725 GHz	5.875 GHz	150 MHz	5.800 GHz	Worldwide
24.000 GHz	24.250 GHz	250 MHz	24.125 GHz	Worldwide
61.000 GHz	61.500 GHz	500 MHz	61.250 GHz	Subject to local acceptance
122.000 GHz	123.000 GHz	1 GHz	122.500 GHz	Subject to local acceptance
244.000 GHz	246.000 GHz	2 GHz	245.000 GHz	Subject to local acceptance

Table: https://en.wikipedia.org/wiki/ISM_band

What is Wi-Fi?

- A Wi-Fi Alliance Trademark
  - Not a strict technical term
- Wi-Fi is commonly used to refer to the 802.11 family of wireless standards
- Wi-Fi can run in ISM bands
- Wi-Fi is designed for shared spectrum






WiFi™

WiFi can now be found almost anywhere.



Current 802.11 Standards

Standard	Data rate [Mbps]	Frequency [GHz]	Channel Access
802.11b	11	2.4	DSSS
802.11g	54	2.4	DSSS, OFDM
802.11a	54	5	OFDM
802.11n	150/300/600	2.4 / 5	DSSS, OFDM, MIMO
802.11ac	1300	5	OFDM, Mu-MIMO

Emerging 802.11 standards

Standard	Data rate [Mbps]	Frequency	Channel Access
802.11ad	>6000	60 GHz	Milimetre waves Very short range
802.11af	10-100	2.4	TV White Spaces Non Line of Sight

The Speed of Wi-Fi

- Wi-Fi Data Rates – 11, 54, 1300mbps
  - Peak raw radio symbol rates
  - Half-duplex, not full duplex!
  - Not actual TCP/IP throughput rates
  - Lower Speeds are realized due to:
    - Protocol overhead
    - Adaptive modulation
- Practical Wi-Fi advice, on a perfect link:
  - TCP/IP throughput is ½ Wi-Fi data rate

Spectrum Access Schemes

- Channel-based access schemes
  - Frequency Division Multiple Access (FDMA)
  - Time division multiple access (TDMA)
  - Code division multiple access (CDMA)
  - Space division multiple access (SDMA)
  - These can be combined!
- Packet-based access schemes
  - Carrier sense multiple access (CSMA)
- Important as they impact performance

802.11 Spectrum Access

WiMax	Dynamic TDMA
LTE	OFDMA / MIMO / SC-FDMA
3G mobile	CDMA
2G mobile	TDMA
Bluetooth	FHSS

802.11a	DSSS, FHSS
802.11b	DSSS, 20 MHz channel
802.11g	OFDM, DSSS
802.11n	OFDM, DSSS, MIMO, 40MHz channel
802.11ac	OFDM, MU-MIMO, 80MHz channel

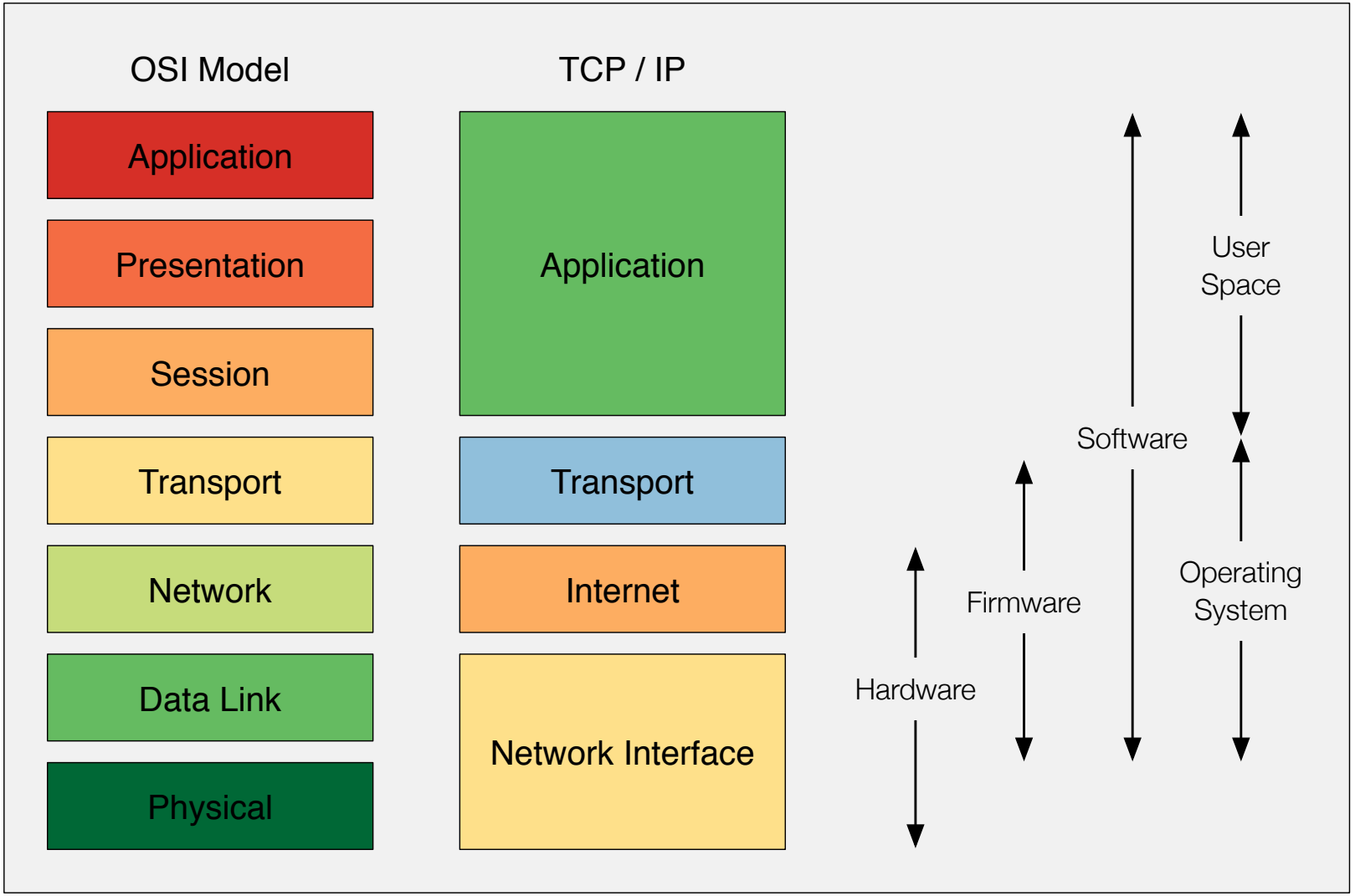
Compatibility of Standards

Access Point

Client

	802.11a	802.11b	802.11g	802.11n	802.11ac
802.11a	Yes			@5GHz	@5GHz
802.11b		Yes	(slower)	(slower)	
802.11g		(slower)	Yes	(slower)	
802.11n	@5GHz	@2.4GHz	@2.4GHz	Yes	(slower)
802.11ac	@5GHz			@5GHz	Yes

Think In Layers



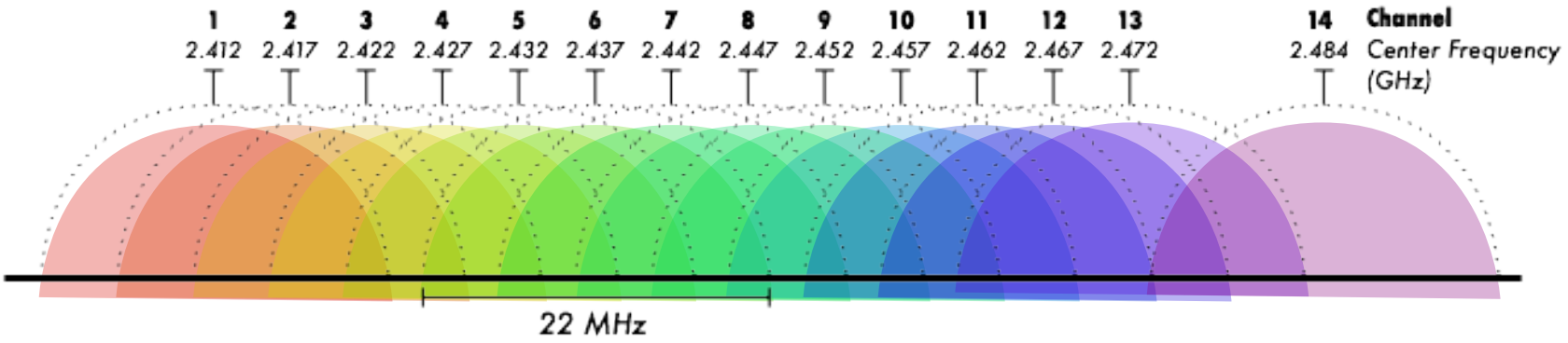
Layers 1 & 2

- WiFi devices must agree on several parameters
- Before they can communicate with each other!

TCP/IP Protocol Stack	
5	Application
4	Transport
3	Internet
2	Data Link
1	Physical

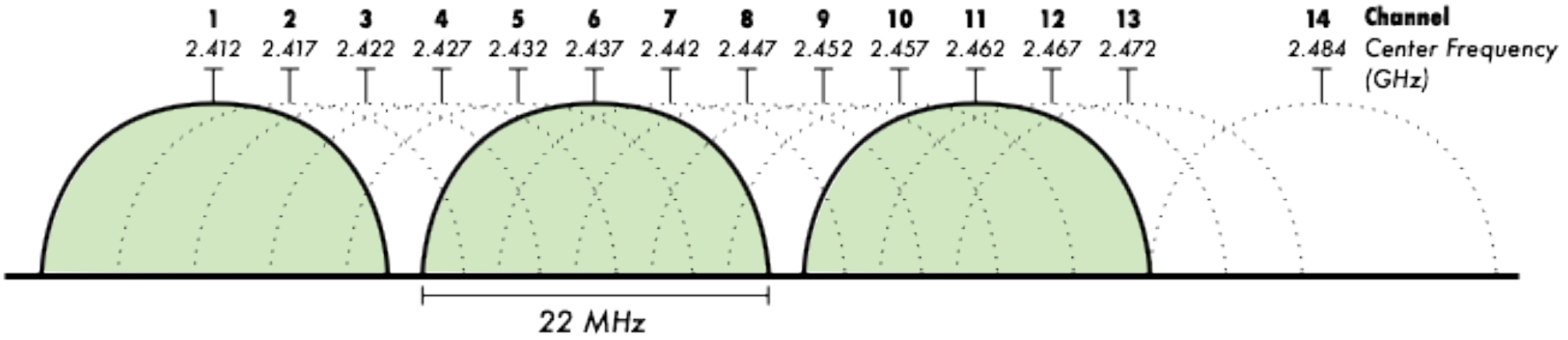
- Frequency:
  - Band, Center, Channel Size
- Radio operating mode:
  - Managed, Station/Client, Ad-Hoc
- Network name (SSID)
- Security features:
  - WPA, WPA2, EAP

802.11 Wi-Fi Channels



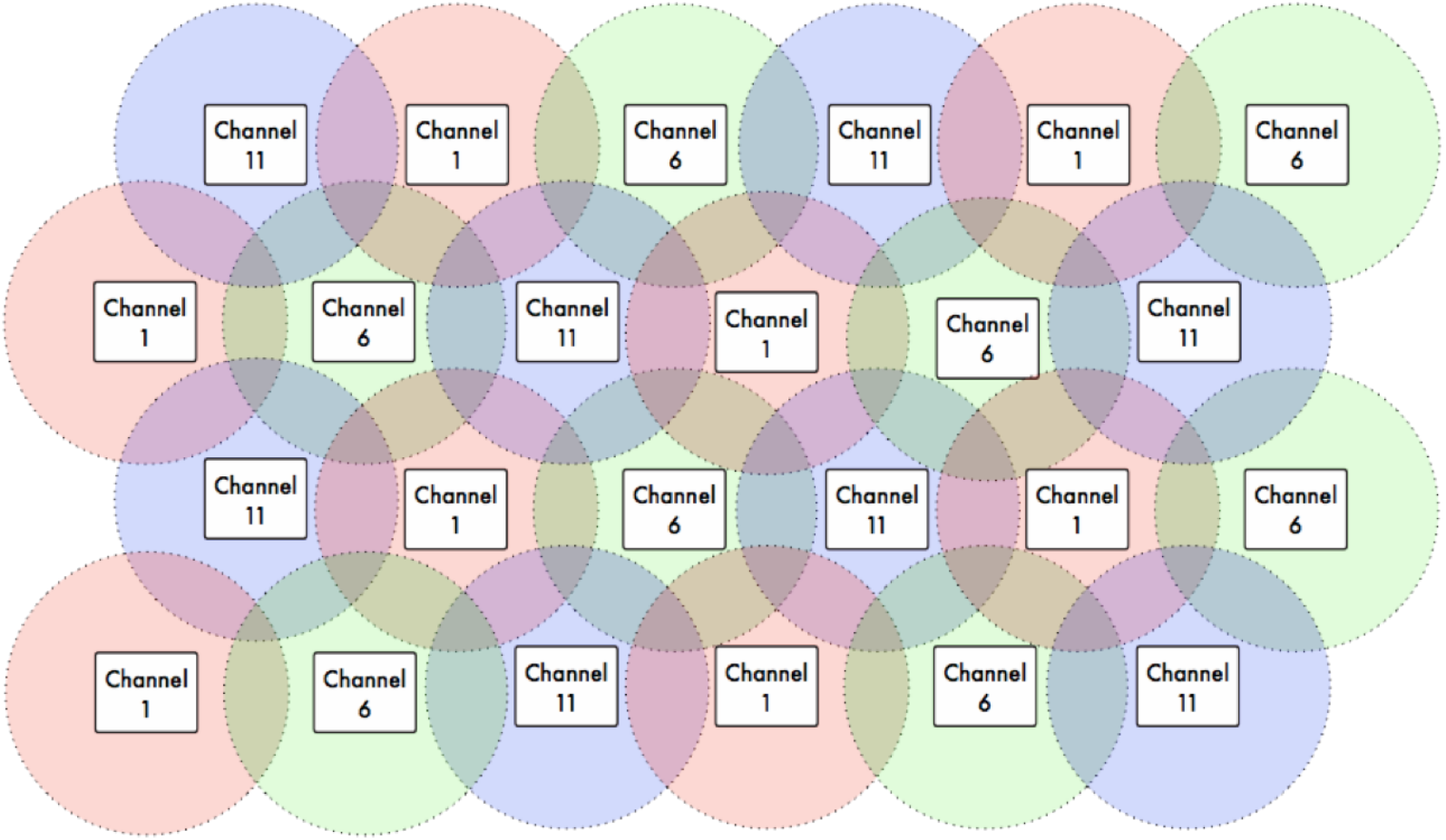
- Frequency bands are divided into channels
- 2.4 GHz has 14 overlapping channels of 22 MHz each
- 5.8 GHz has 5 non-overlapping channels of 20 MHz each
- Wi-Fi devices must use the same channel
- Wi-Fi devices send and receive on the same channel
  - This kind of connection is called ***half-duplex***.

Non-Overlapping Channels 1,6,11,14



- Not All Countries Allow All Channels!
- Channel 14 is not allowed in the USA

Three Channel Coverage Design



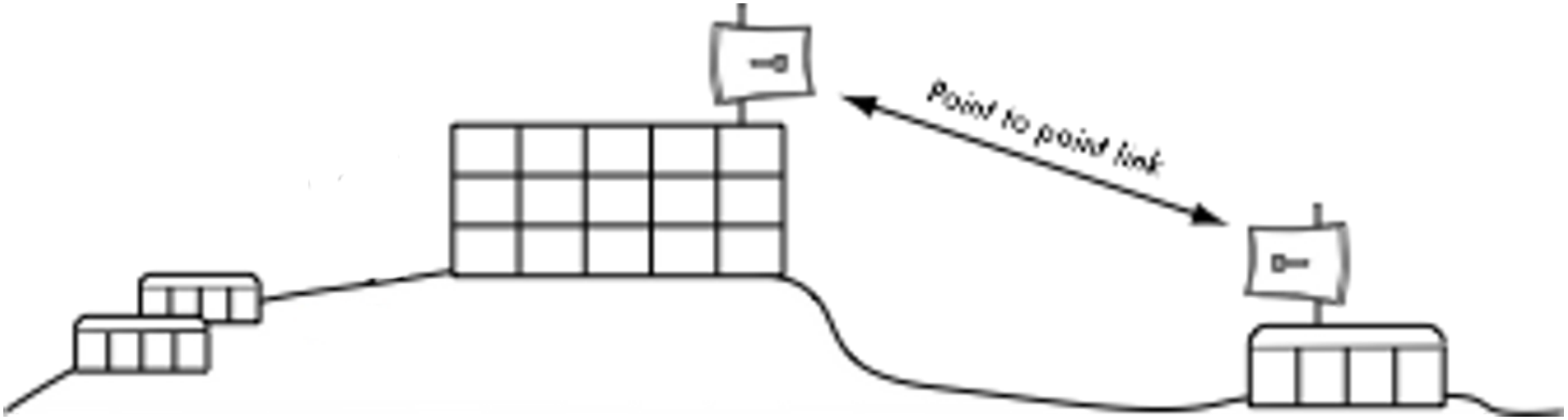
Remember this is theory!
Reality does not look this nice.

Wireless Network Topologies

- Point to Point
- Point to Multipoint
- Multipoint to Multipoint

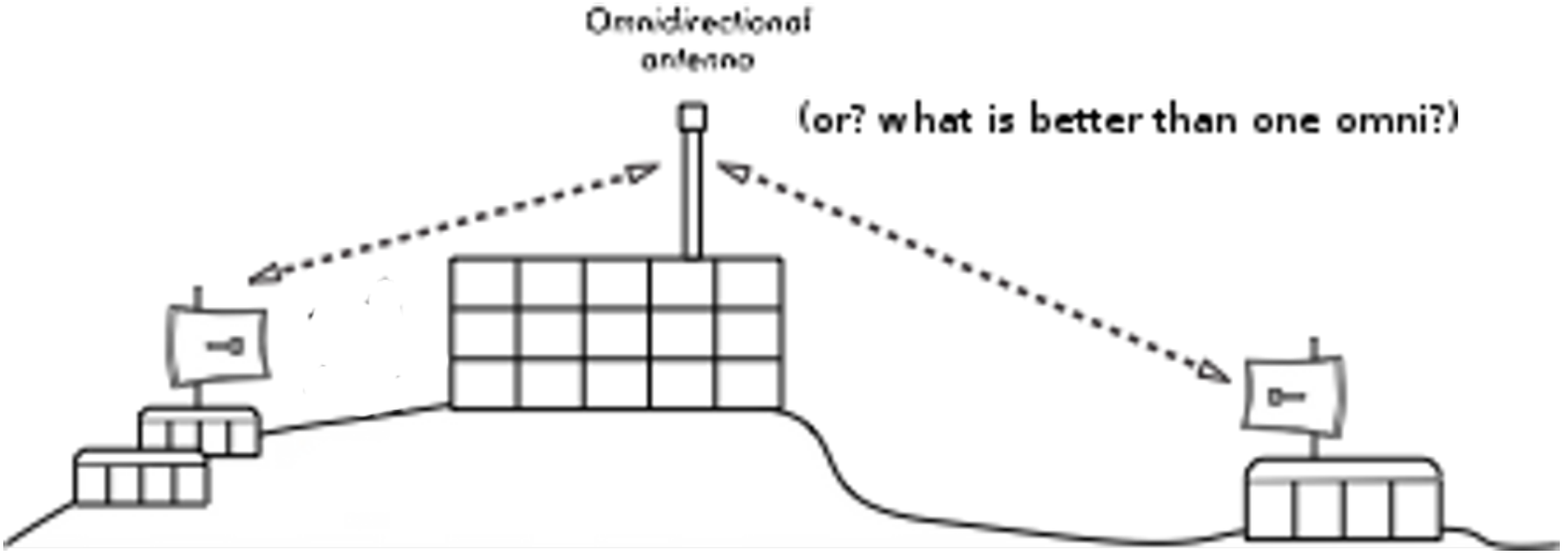
Point-to-Point

- The simplest connection is a ***point-to-point*** link
- These links can work over great distances



Point-to-Multipoint

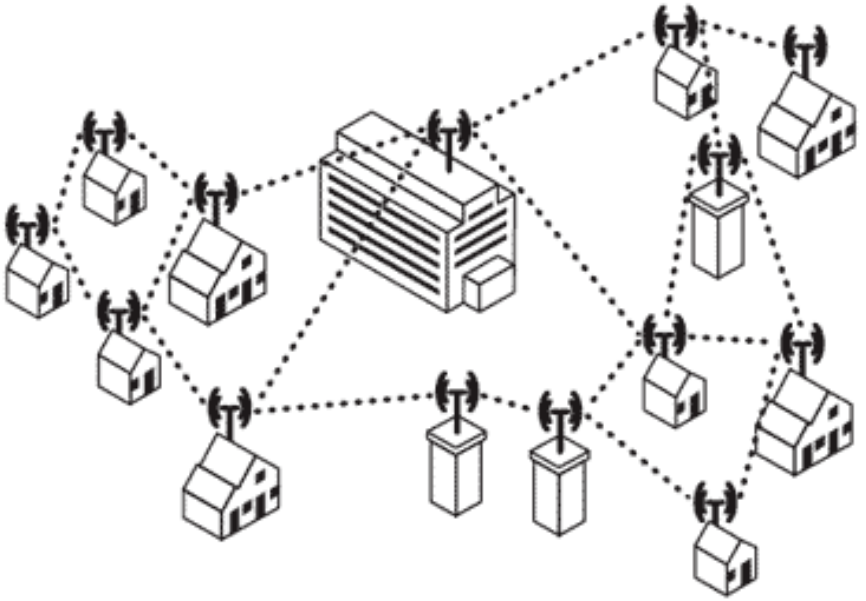
When more than one node communicates with a central point, this is a ***point-to-multipoint*** network.



Multipoint-to-Multipoint

Any node ***may*** communicate with any other

This can be an “ad-hoc” or a planned **mesh**



Wi-Fi Radio Modes

- Wi-Fi devices can operate in one of these modes
  - ***Master*** (access point)
  - ***Managed*** (also known as ***client*** or ***station***)
  - ***Ad-hoc*** (used for mesh networks)
  - ***Monitor*** (not normally used for communications)
- Only one mode is supported at a time

Master (Infrastructure) Mode

Master mode (also called AP or infrastructure mode) is used to provide an infrastructure with an access point connecting different clients. The access point creates a network with a specified name (called the ***SSID***) and channel, and offers network services on it.

WiFi devices in master mode can only communicate with devices that are associated with it in ***managed*** mode.

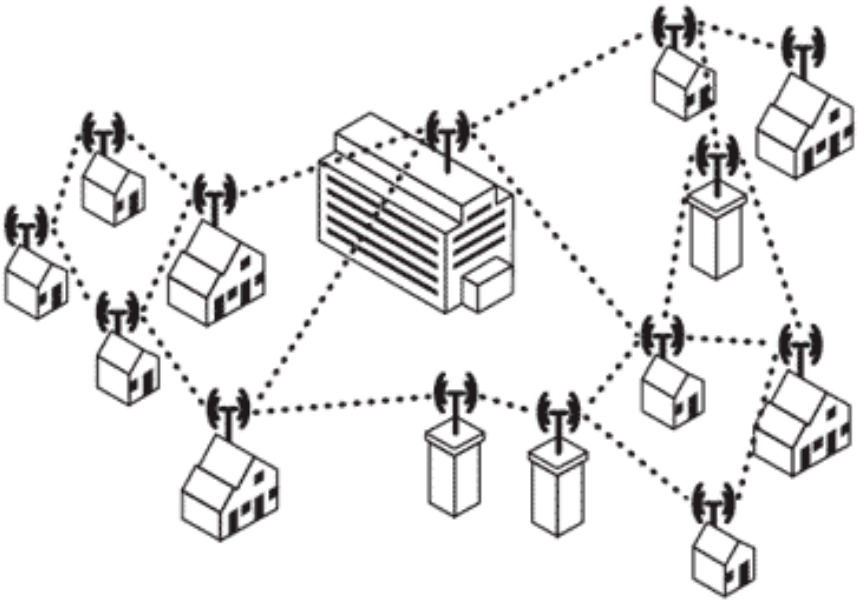
Managed Mode

Managed mode is sometimes also referred to as ***client mode***. Wireless devices in managed mode will join a network created by a master, and will automatically change their channel to match it.

Clients using a given access point are said to be ***associated*** with it. Managed mode radios do not communicate with each other directly, and will only communicate with an associated master (and only with one at a time).

Ad-Hoc Mode

Ad-hoc mode is used to create one to one connections and mesh networks.
In this case, there is no master and client.
Devices must must agree on a network name and channel.

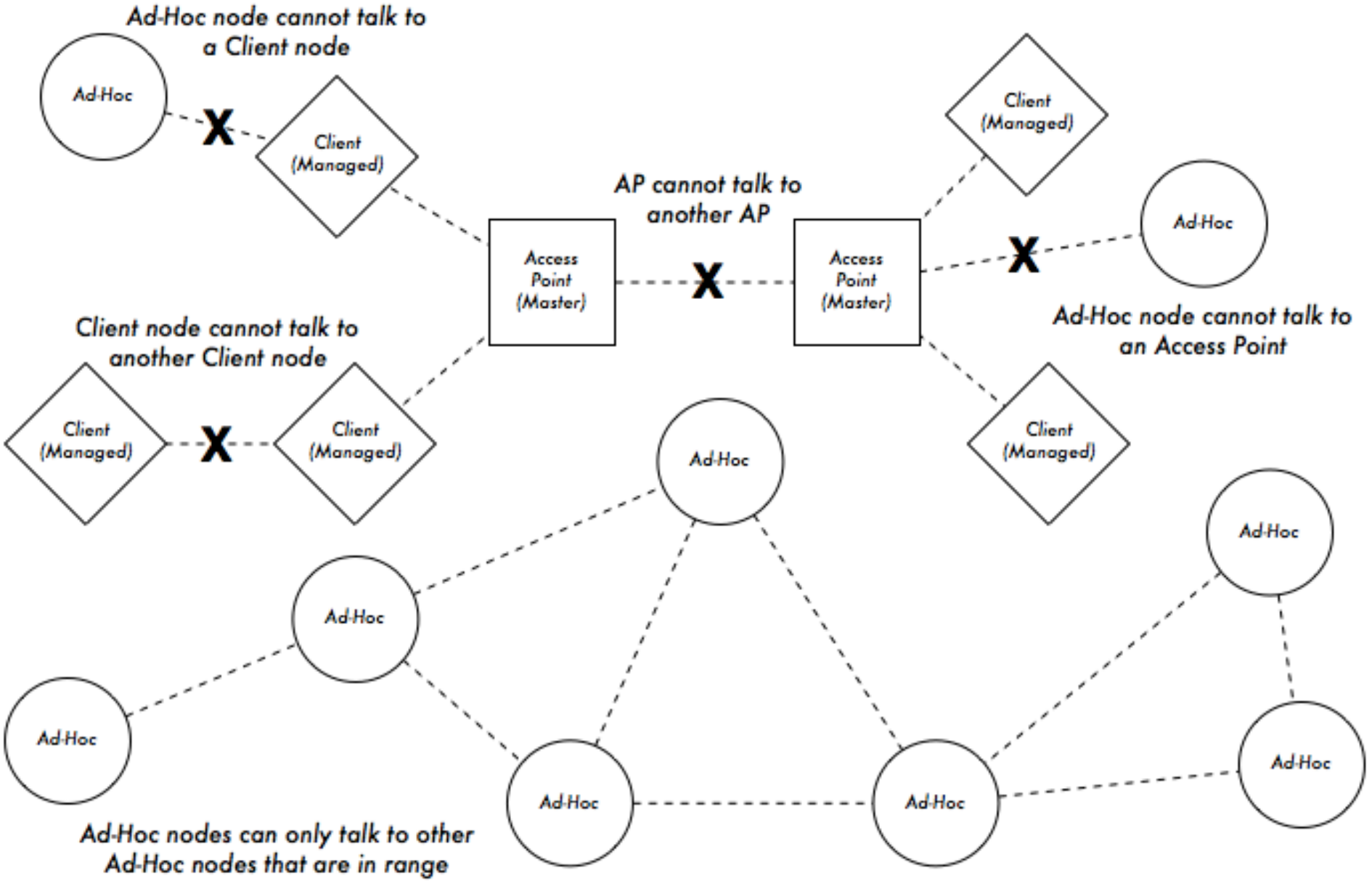


Monitor Mode

Monitor mode is used to passively listen to all radio traffic on a given channel. This is useful for:

- Analyzing wireless link problems
- Observing spectrum usage
- Security maintenance tasks

Wi-Fi Radio Modes In Action



Wireless Distribution System (WDS)

- Access Points can communicate with each other!
- But there can be many problems
  - Cross-vendor compatibility
  - Maximum throughput is halved at each hop
  - Typically supports only 5 APs at a time
- WDS is rarely needed and not recommended.

Wi-Fi Does Not Route Traffic

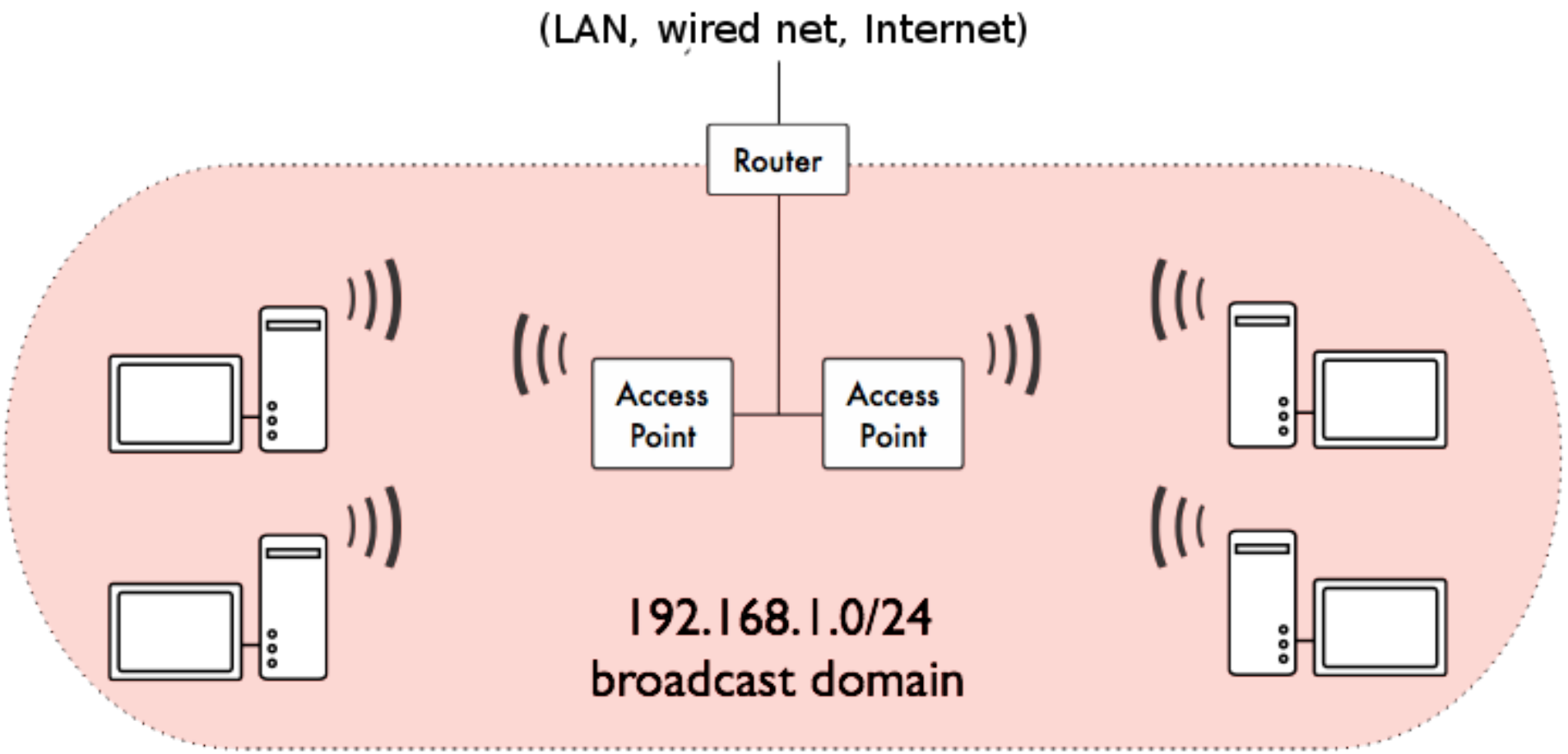
- 802.11 Wi-Fi provides a link-local connection.
- Wi-Fi does ***not*** provide any routing functionality!
- Routing is implemented by higher level protocols.

TCP/IP Protocol Stack	
5	Application
4	Transport
3	Internet
2	Data Link
1	Physical

Bridged Networking

- Appropriate for simple networks
- **Advantages**
  - Very simple configuration
  - Roaming works very well
- **Disadvantages**
  - Efficiency falls as nodes are added
  - All broadcast traffic is repeated
  - Unstable on larger networks

Bridged Access Points



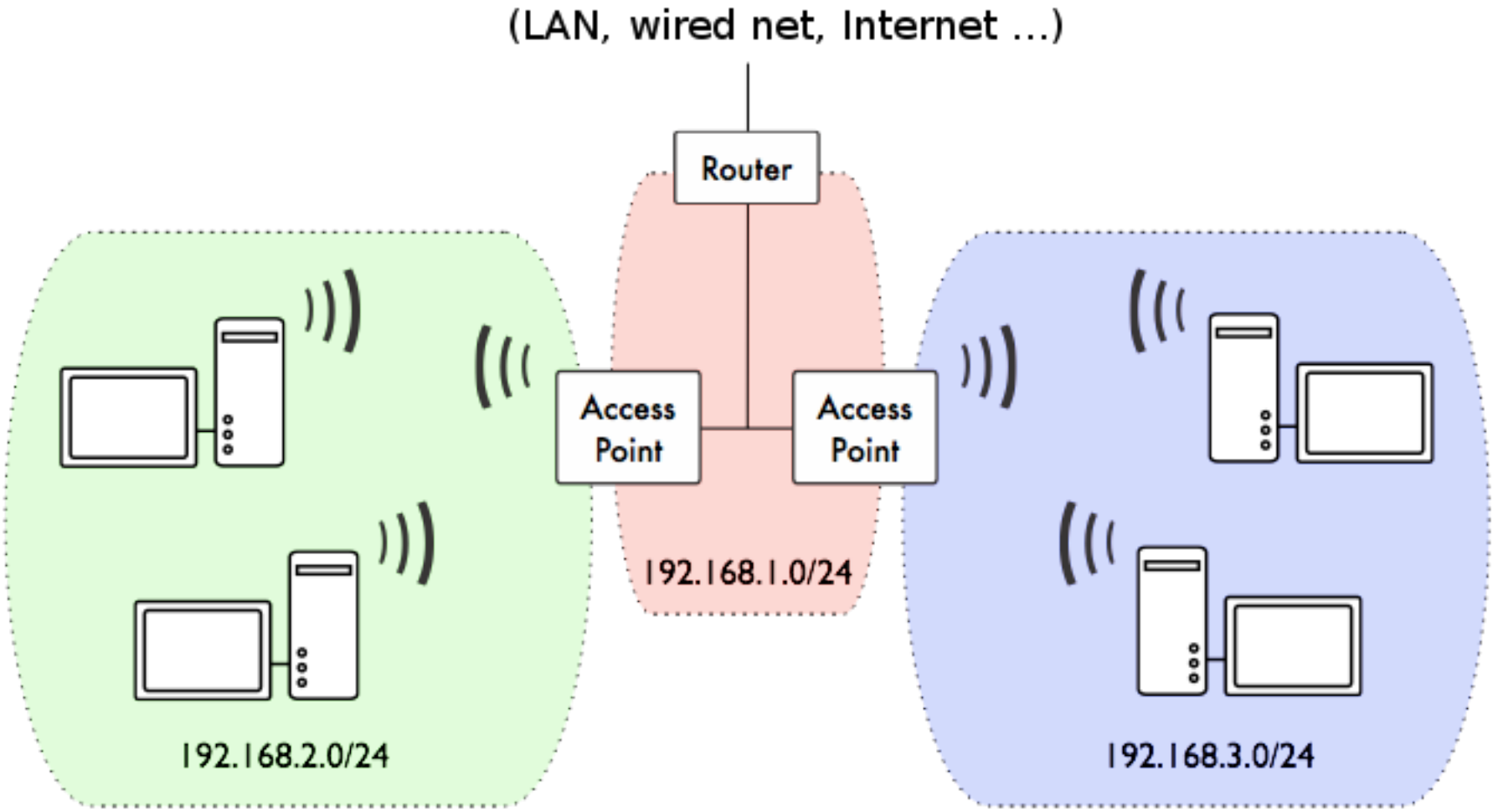
Routed Networking

- Route between nodes for large networks
- Static Routing
  - Point-to-point links
  - Simple networks
- Dynamic Routing
  - RIP is a very old protocol with many problems
  - OSPF is a modern protocol for dynamic routing
  - RIP and OSPF do not perform well on unstable backbones
- Mesh Routing
  - Standards & proprietary protocols available
  - Can perform better than OSPF on unstable networks

Routed Networking

- Appropriate for large, campus, or metro networks
- **Advantages**
  - Limited broadcast domains
  - More efficient use of radio bandwidth
  - Many protocols & bandwidth management tools
- **Disadvantages**
  - More complex configuration
  - Roaming between APs is more difficult

Routed Access Points



Frequently Asked Questions

Frequently Asked Questions

How fast?
How far?
How many clients?
Are all my devices compatible?
What should I buy?

What We Can Do Today

- 10 Mbps over 1 km for $100
- 300 Mbps over 5 km for $200
- 1 Gbps over 10 km for $2000
- Up to 100 km distance (and beyond)
- Simple hotspots for <$50 per AP
- Managed access networks for $100 per AP

How Many Clients?

- How many end users on one AP?
  - 100 moderate users
  - 10-30 heavy users
- Limitations
  - Radio Spectrum
  - Slowest Clients
  - Backhaul & Core Network
  - Access Point CPU / Packets Per Second

Problems For The Future

- Bring Your Own Device (BYOD) means 2-4 devices per person
- Power over Ethernet (PoE) at 100mbps is no longer enough
- 1gbps Ethernet is not enough for some 802.11ac access points
- Network security is difficult, and getting more difficult
- How will you manage your users?

Learning More

Network Startup Resource Center
http://nsrc.org
ICTP Wireless | T/ICT4D Lab
http://wireless.ictp.it/
Wireless Networking for the Developing World
http://wndw.net
ICTP UNESCO Wireless Training Kit
http://140.105.28.115/groups/wtkit/

Thank you!

Questions and comments?

Email your workshop mailing list!