Internet access and backbone technology

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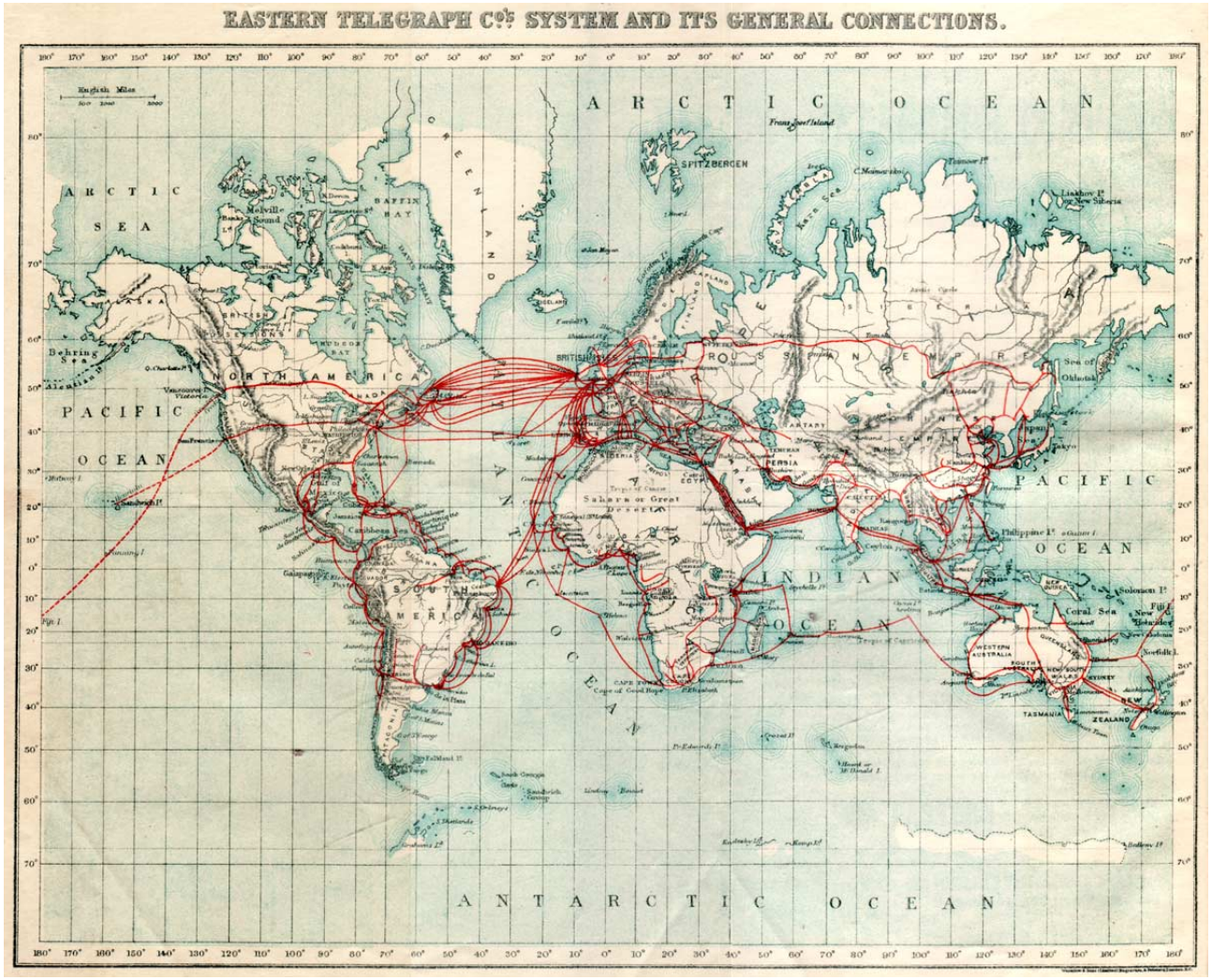
COMS 6181 – Spring 2015

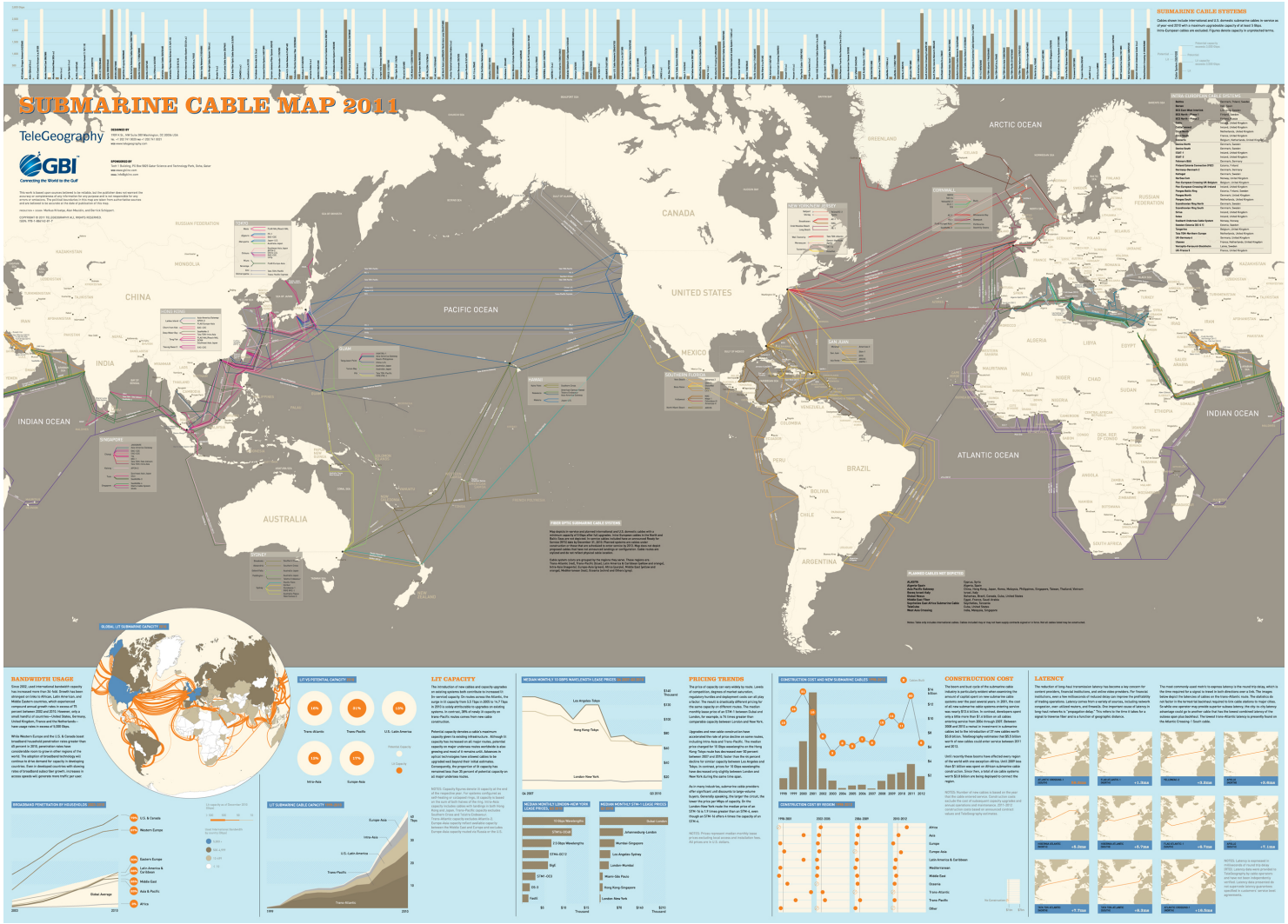
Key objectives

- How does the Internet backbone work?
- How does Internet routing work?
- What is spectrum and its characteristics?
- What is the difference between Wi-Fi and cellular?

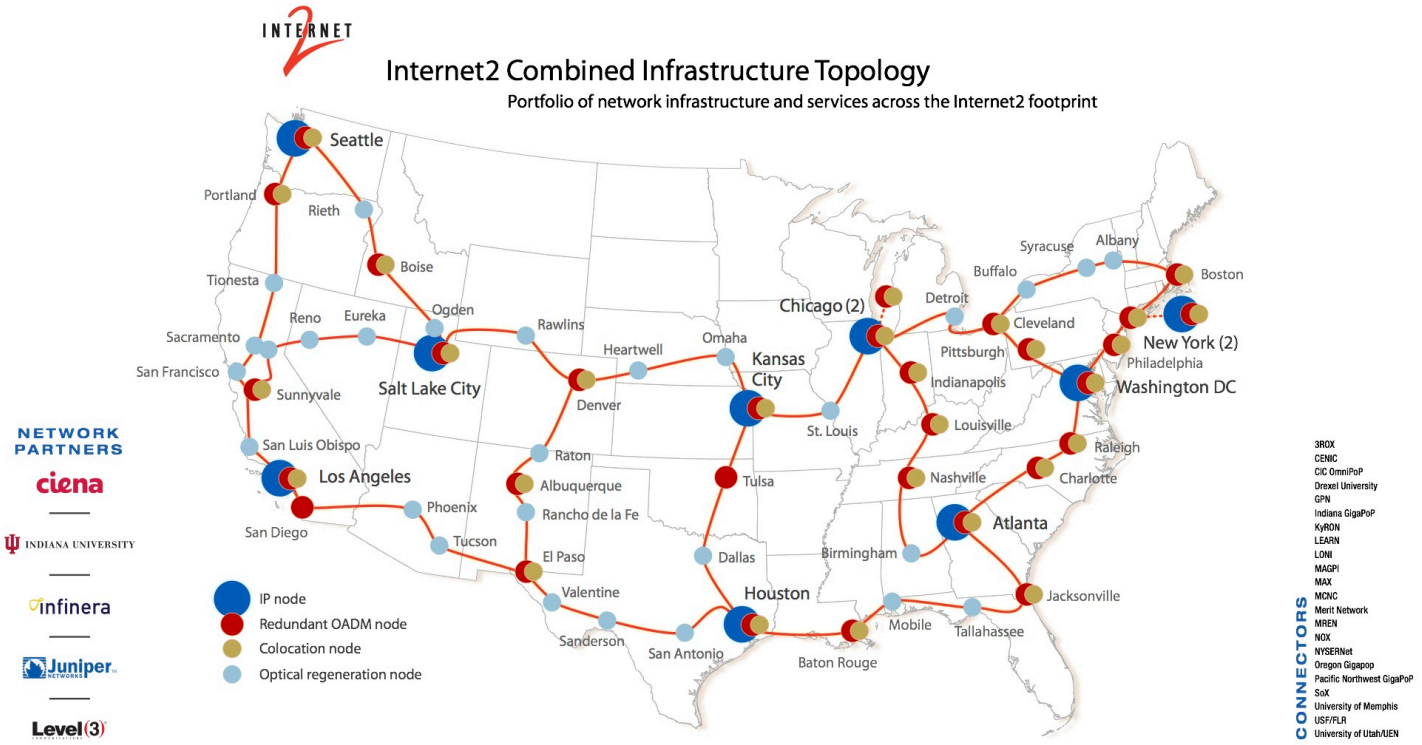
1901 “data” backbone



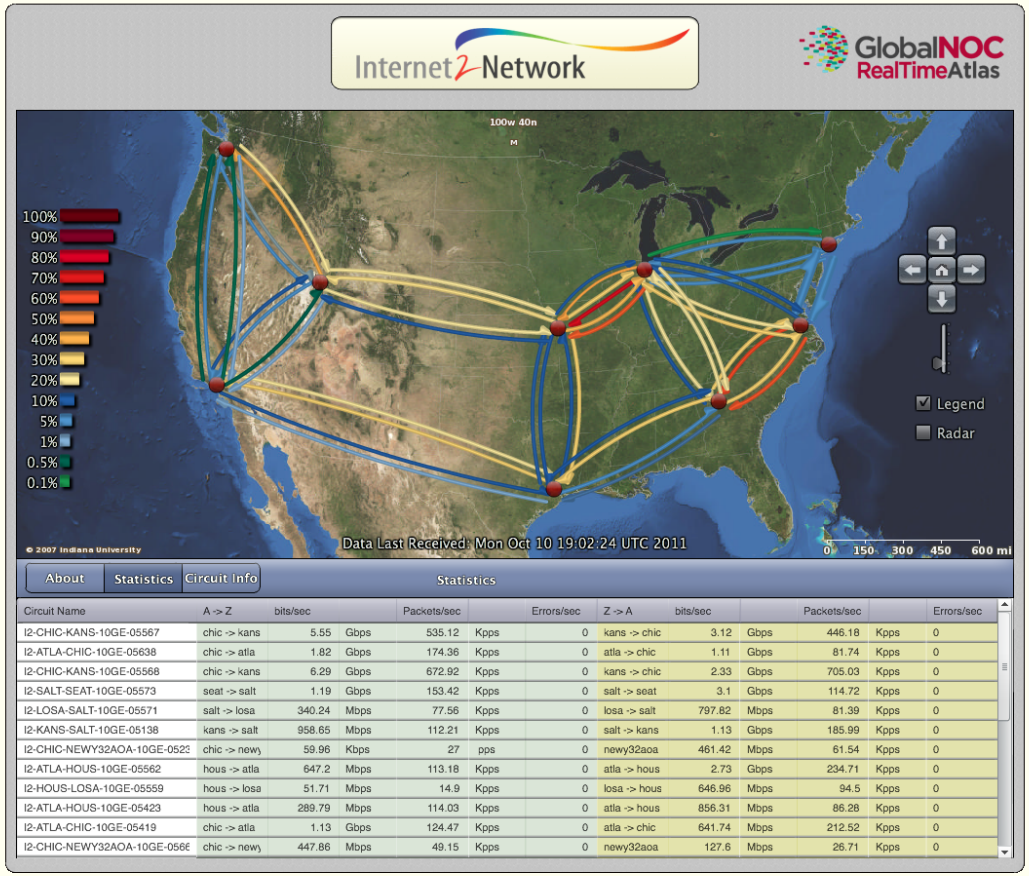
Submarine cable map



Backbone: Internet2 architecture



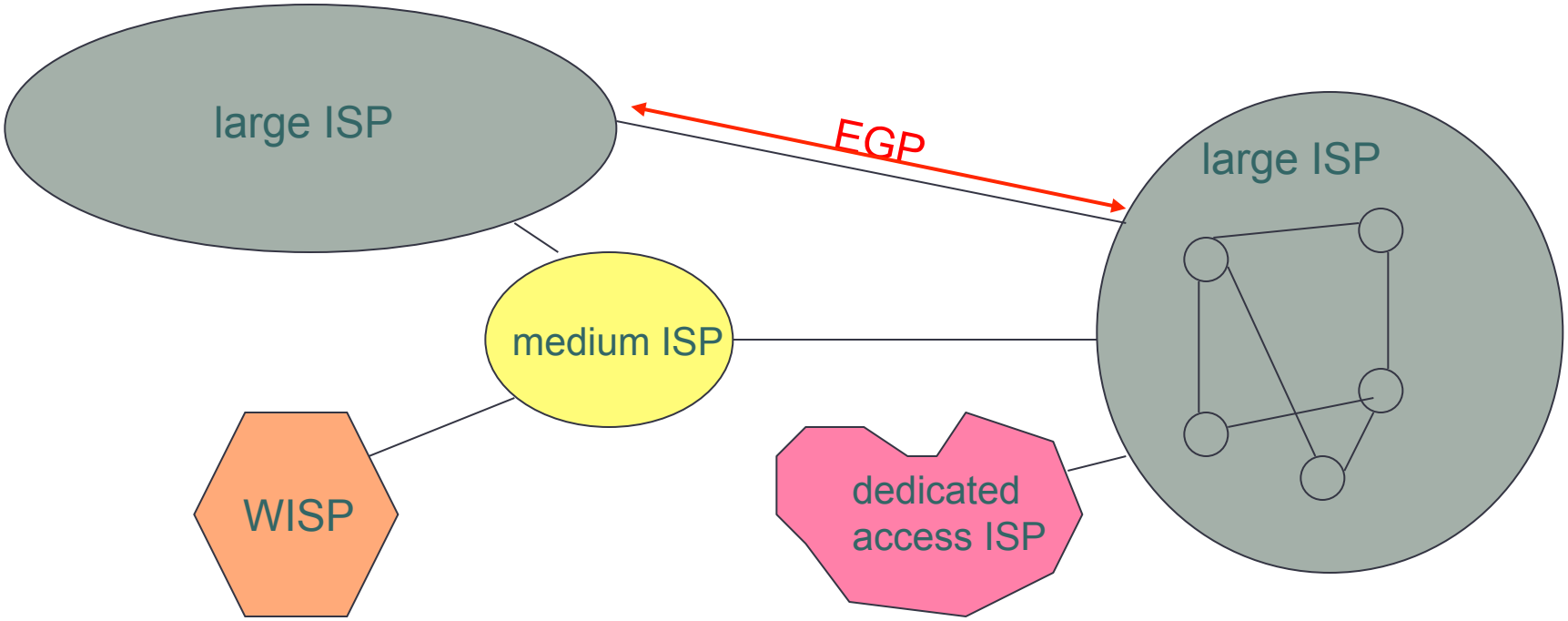
Internet2 loading



Circuit Name	A -> Z	bits/sec		Packets/sec		Errors/sec	Z -> A	bits/sec		Packets/sec		Errors/sec
I2-CHIC-KANS-10GE-05567	chic -> kans	5.55	Gbps	535.12	Kpps	0	kans -> chic	3.12	Gbps	446.18	Kpps	0
I2-ATLA-CHIC-10GE-05638	chic -> atla	1.82	Gbps	174.36	Kpps	0	atla -> chic	1.11	Gbps	81.74	Kpps	0
I2-CHIC-KANS-10GE-05568	chic -> kans	6.29	Gbps	672.92	Kpps	0	kans -> chic	2.33	Gbps	705.03	Kpps	0
I2-SALT-SEAT-10GE-05573	seat -> salt	1.19	Gbps	153.42	Kpps	0	salt -> seat	3.1	Gbps	114.72	Kpps	0
I2-LOSA-SALT-10GE-05571	salt -> losa	340.24	Mbps	77.56	Kpps	0	losa -> salt	797.82	Mbps	81.39	Kpps	0
I2-KANS-SALT-10GE-05138	kans -> salt	958.65	Mbps	112.21	Kpps	0	salt -> kans	1.13	Gbps	185.99	Kpps	0
I2-CHIC-NEWY32AOA-10GE-0523	chic -> newy	59.96	Kbps	27	pps	0	newy32aoa	461.42	Mbps	61.54	Kpps	0
I2-ATLA-HOUS-10GE-05562	hous -> atla	647.2	Mbps	113.18	Kpps	0	atla -> hous	2.73	Gbps	234.71	Kpps	0
I2-HOUS-LOSA-10GE-05559	hous -> losa	51.71	Mbps	14.9	Kpps	0	losa -> hous	646.96	Mbps	94.5	Kpps	0
I2-ATLA-HOUS-10GE-05423	hous -> atla	289.79	Mbps	114.03	Kpps	0	atla -> hous	856.31	Mbps	86.28	Kpps	0
I2-ATLA-CHIC-10GE-05419	chic -> atla	1.13	Gbps	124.47	Kpps	0	atla -> chic	641.74	Mbps	212.52	Kpps	0
I2-CHIC-NEWY32AOA-10GE-056	chic -> newy	447.86	Mbps	49.15	Kpps	0	newy32aoa	127.6	Mbps	26.71	Kpps	0

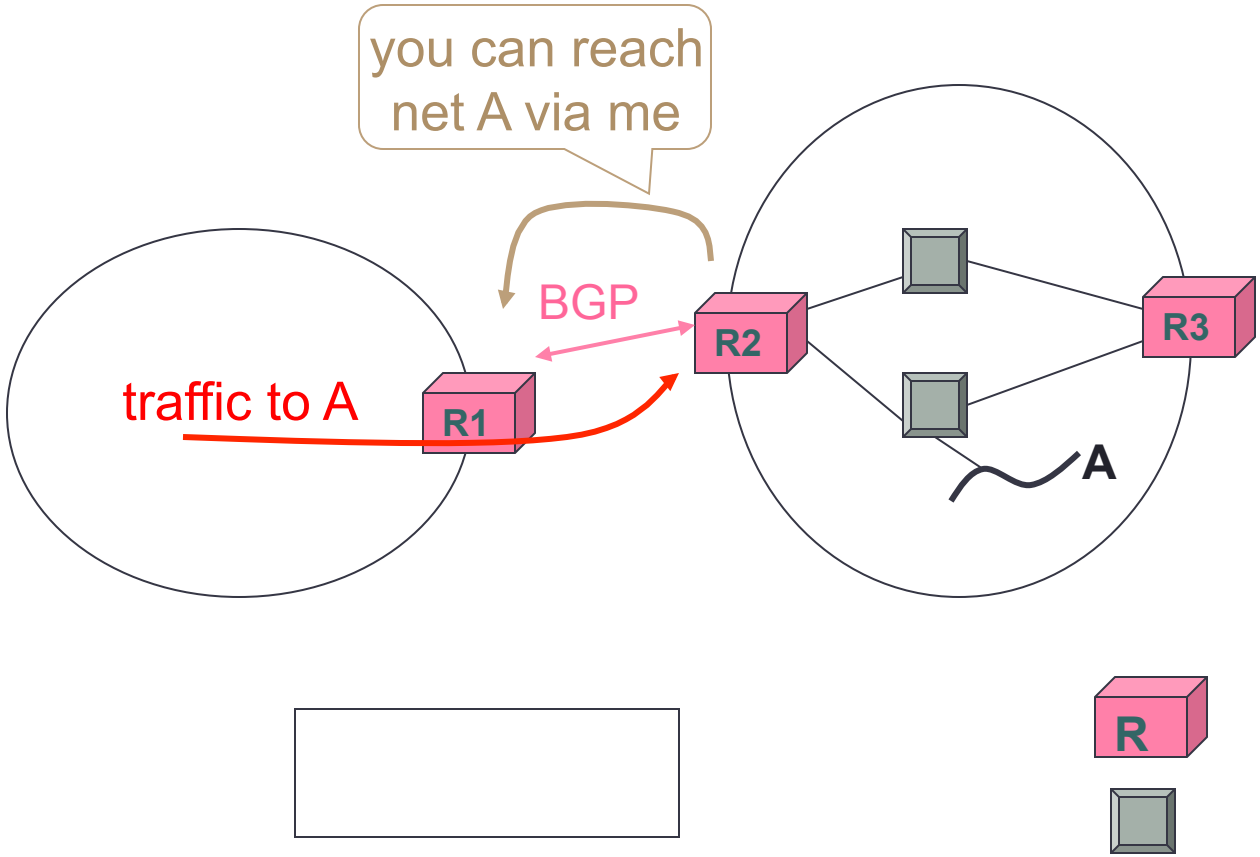
http://atlas.grnoc.iu.edu/I2.html

Internet topology



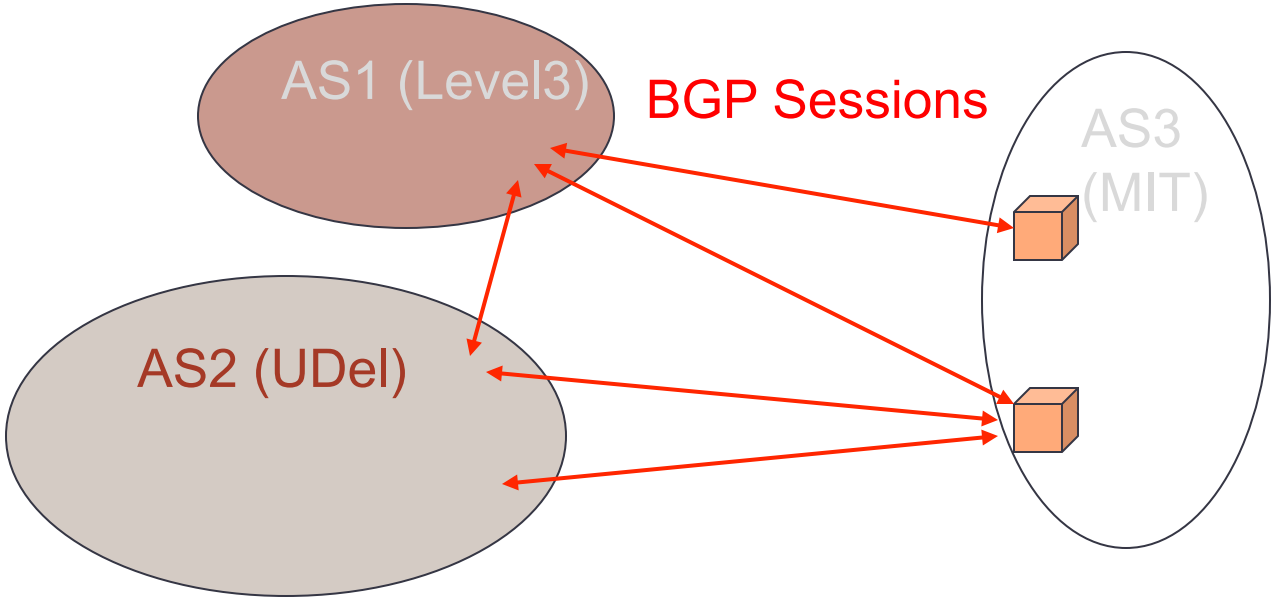
- AS (Autonomous System)
- EGP (External Gateway Protocol)

Purpose: to share connectivity information

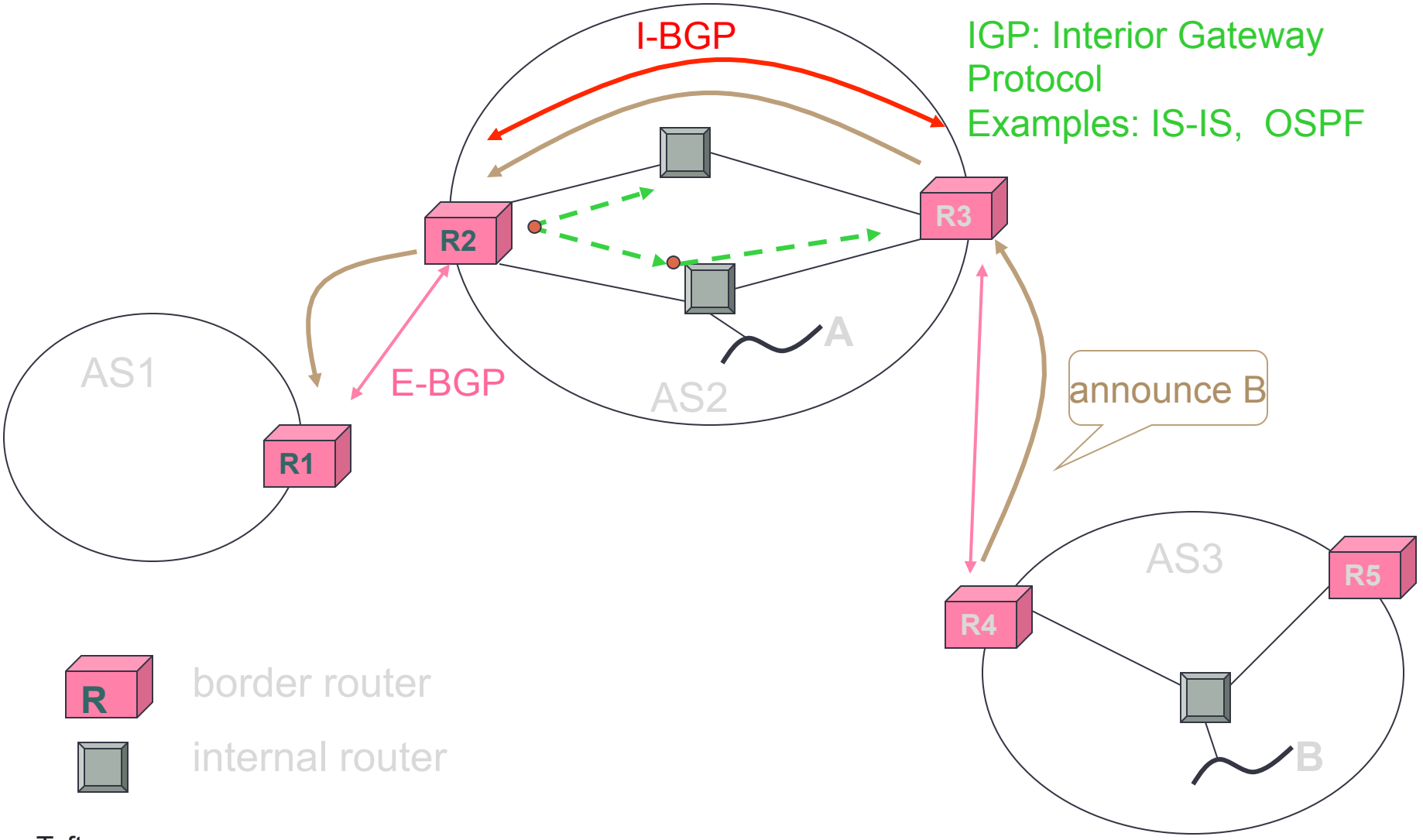


BGP sessions

- One router can participate in many BGP sessions.
- *Initially* … node advertises ALL routes it wants neighbor to know (could be >50K routes)
- *Ongoing* … only inform neighbor of changes



Routing protocols



Address arithmetic: address blocks

- The <address/prefix> pair defines an address block:
- Examples:
  - 128.15.0.0/16 => [128.15.0.0 - 128.15.255.255]
  - 188.24.0.0/13 => [188.24.0.0 - 188.31.255.255]
    consider 2nd octet in binary:

198.**00011000**.0.0

13th bit settable

- Address block sizes
  - a /13 address block has 2^{32-13} addresses (/16 has 2^{32-16})
  - a /13 address block is 8 times as big as a /16 address block because $2^{32-13} = 2^{32-16} * 2^{3}$

CIDR: longest prefix match

- Because prefixes of arbitrary length allowed, overlapping prefixes can exist
- Example:
  router hears 124.39.0.0/16 from one neighbor
  and 124.39.11.0/24 from another neighbor
- Router forwards packet according to most specific forwarding information, called *longest prefix match*
  - Packet with destination 124.39.11.32 will be forwarded using /24 entry.
  - Packet w/destination 124.39.22.45 will be forwarded using /16 entry

Four basic BGP messages

- *Open*:
  Establishes BGP session (uses TCP port 179)
- *Notification*:
  Report unusual conditions
- *Update*:
  Inform neighbor of new routes that have become active
  Inform neighbor of old routes that have become inactive
- *Keepalive*:
  Inform neighbor that connection is still viable

BGP attributes

- ORIGIN:
  - Who originated the announcement? Where was a prefix *injected* into BGP?
  - IGP, EGP or Incomplete (often used for static routes)
- AS-PATH:
  - a list of AS's through which the announcement for a prefix has passed
  - each AS prepends its AS # to the AS-PATH attribute when forwarding an announcement
  - pick shortest route
  - useful to detect and prevent loops

Prefix	Next hop	AS Path
128.73.4.21/21	232.14.63.4	1239 701 3985 631

BGP looking glass example

http://www.cogentco.com/en/network/looking-glass (ASN 174)

oulu.fi (University)

```
BGP routing table entry for 130.231.0.0/16, version 3124599241
Paths: (1 available, best #1, table Default-IP-Routing-Table)
  2914 2914 2603 1741
    130.117.14.102 (metric 10190091) from 154.54.66.76 (154.54.66.76)
      Origin IGP, metric 4294967294, localpref 100, valid, internal, best
      Community: 174:11100 174:20666 174:21100 174:22012
```

NTT-COMMUNICATIONS-2914

NORDUNET

FUNET

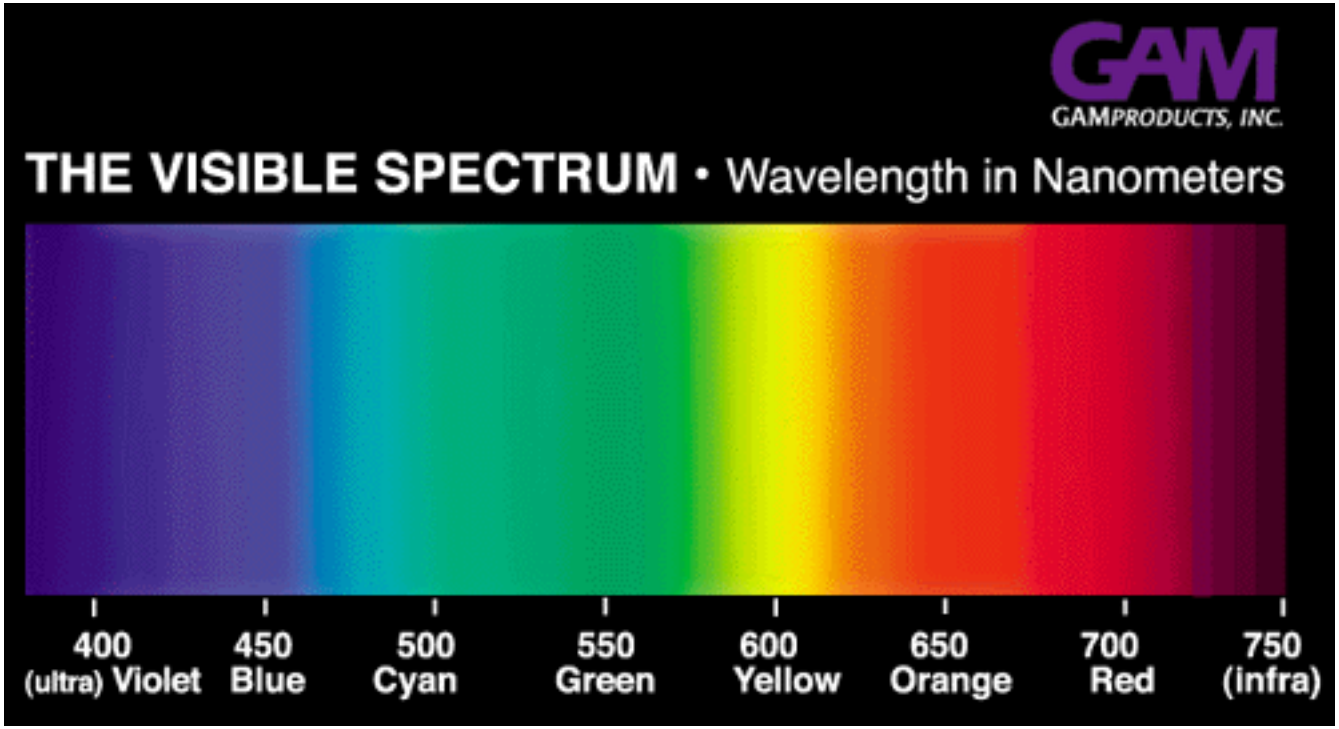
AS whois: http://viewdns.info/asnlookup/

WIRELESS NETWORKS

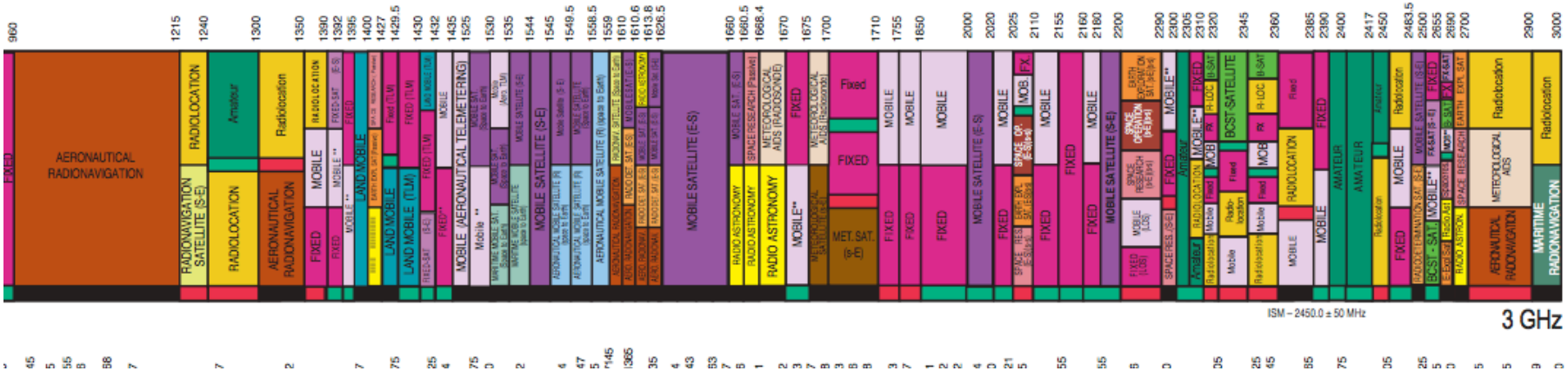
Frequencies

- Licensed vs. unlicensed
  - Unlicensed = ISM (door openers to WiFi) + UNII
    - 902-928 MHz (26 MHz - UHF)
    - 2.450 – 2.5 GHz (50 MHz - 802.11b/g)
    - 5.125-5.25 (125 MHz), 5.25-5.35, 5.5250-5.8250, 5.650 – 5.925 GHz
  - + whiteband
- Roughly:
  - lower frequency → longer range
  - but smaller capacity (smaller bands)
  - 2.45 GHz: microwave oven (interference)
  - 2.5 GHz: foliage issues (beware pine needles!)
  - visible light (~380-750 nm) = 400-789 THz
- Same technology may be used in different frequency bands
  - e.g., WiMAX: 700 MHz, 2.3, 2.4, 2.5, 5.8 GHz

Visible light spectrum

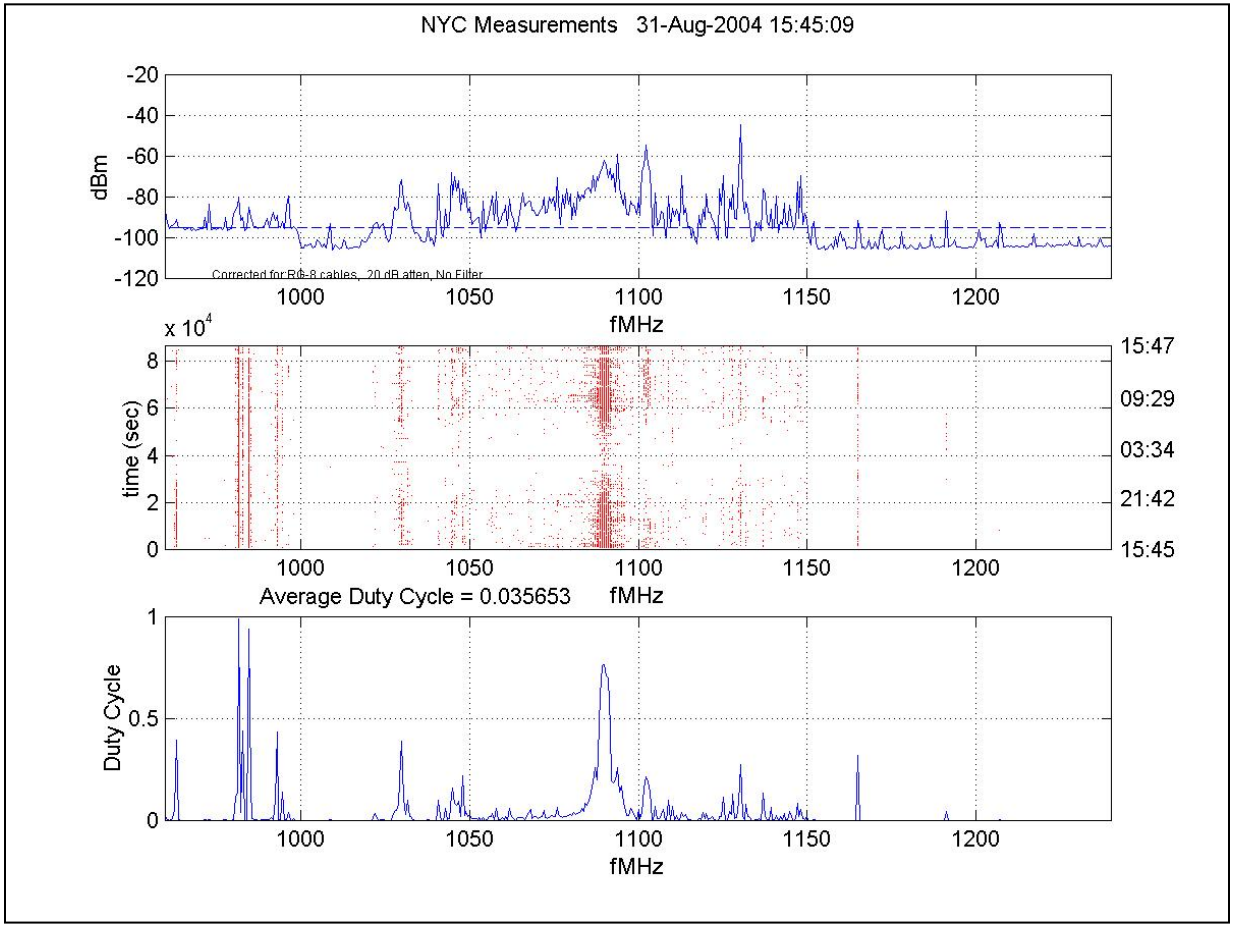


Radio spectrum 1-3 GHz



http://www.ntia.doc.gov/osmhome/allochrt.pdf

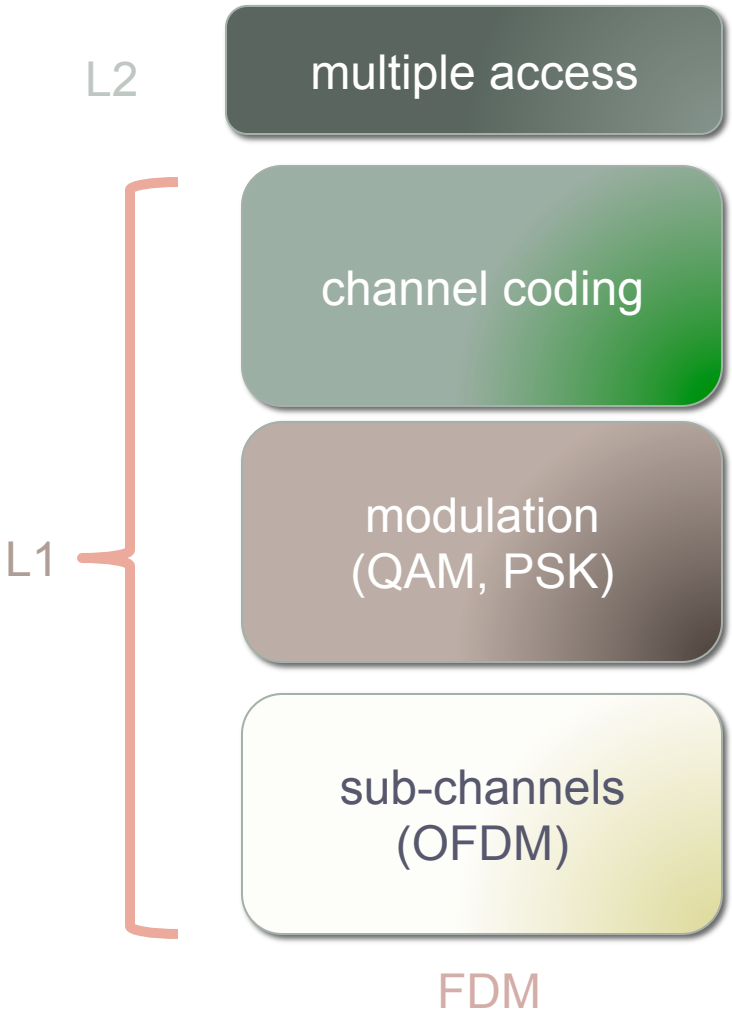
But often lightly used



http://www.sharedspectrum.com/measurements/

NYC, August 2004

The wireless “stack”



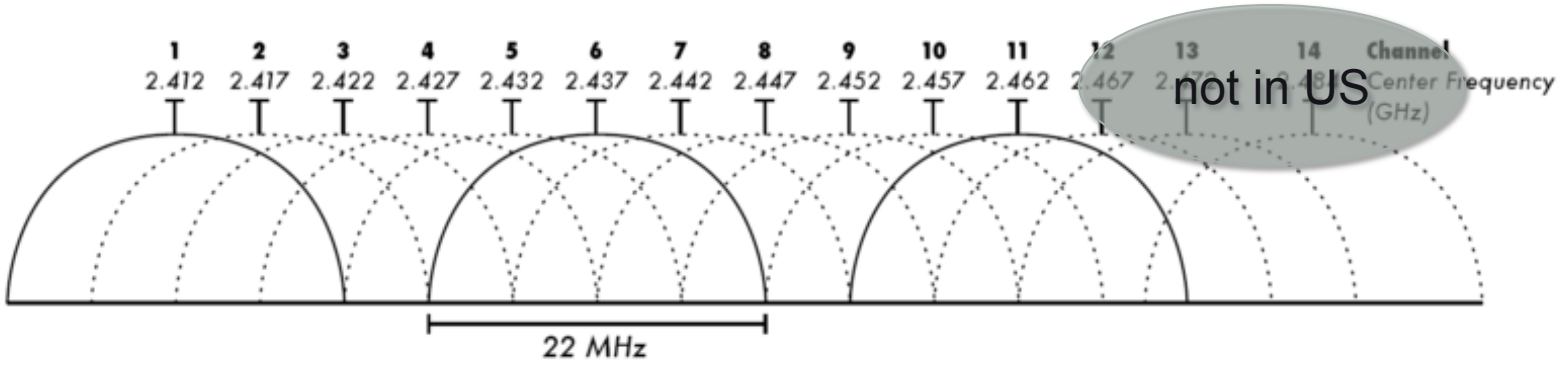
protect against bit errors

bits into frequency & phase

large number of orthogonal channels

WiFi

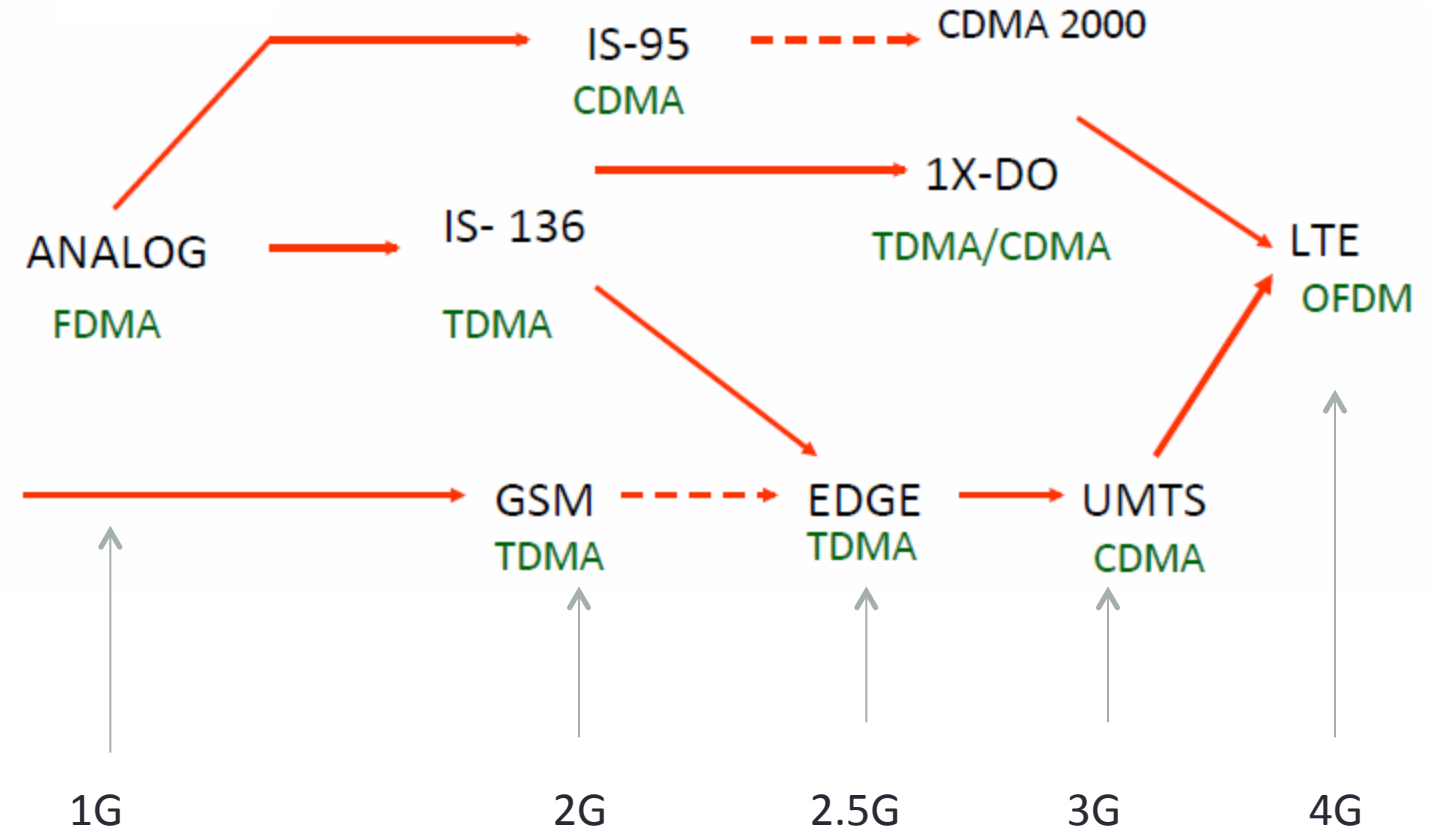
- 802.11b: spread-spectrum
  - 83.5 MHz @ 2.4 GHz: CCK using QPSK
  - 1 Mb/s - 11 Mb/s nominal, 4.5 Mb/s typical
  - 11 channels, some countries 2, 4 or 14; 1-6-11 typical
- 802.11a: OFDM
  - 480 MHz in 24 (US) 20 MHz channels @ 5 GHz
  - 23 Mb/s typical, 54 Mb/s max.
- 802.11g
  - 2.4 GHz
  - 23 Mb/s typical, 54 Mb/s max.
- 802.11n: MIMO
  - 2.4 or 5 GHz
  - 74 Mb/s typical, 300 Mb/s max.



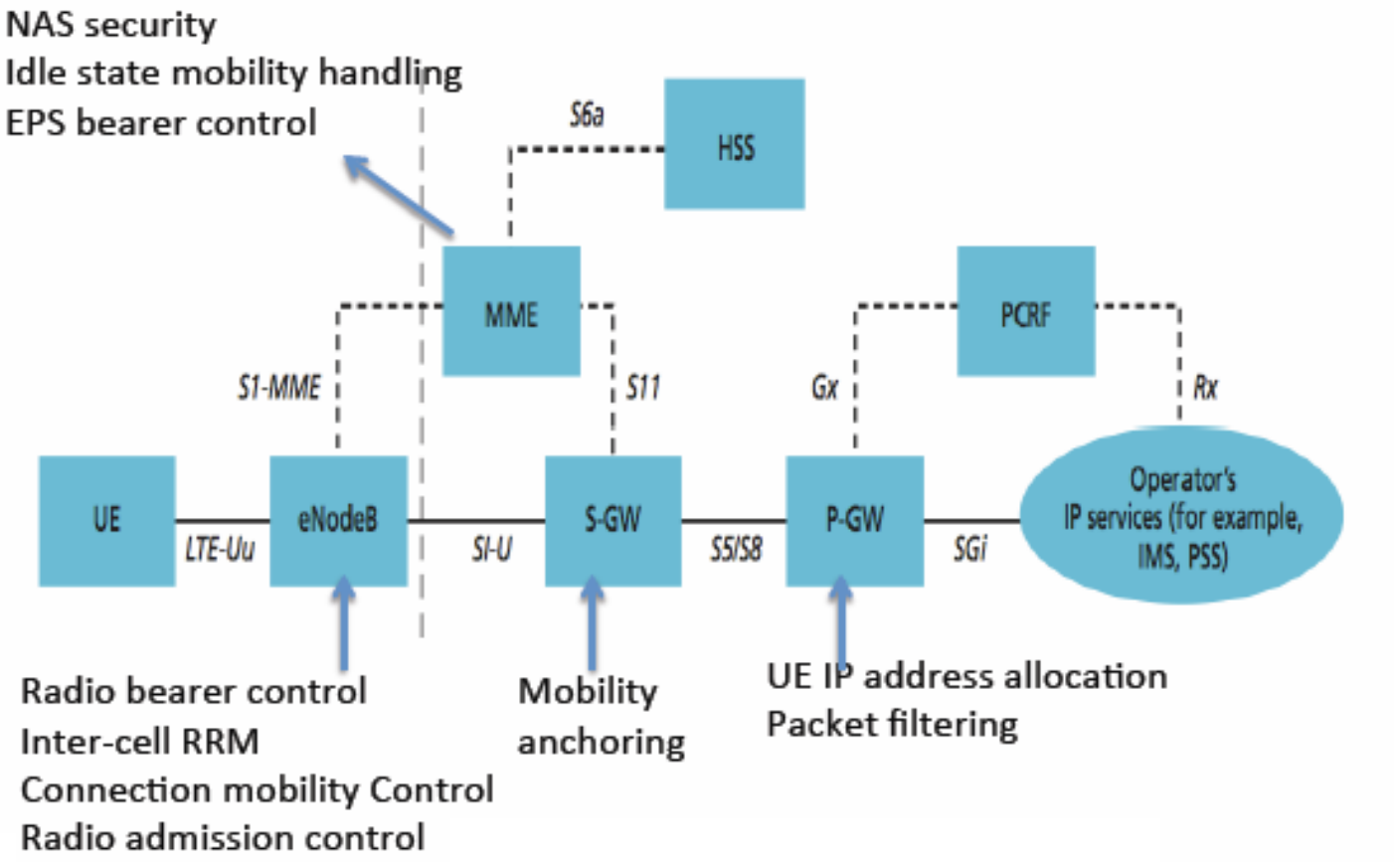
Cellular wireless technologies

- Cell radius: hundreds of m to 35 km (GSM)
  - power-controlled
  - also: macro cell (tower), micro cell (below roof level), pico cell (indoor)
  - 900 or 1800 MHz
    - US: 850, 1900 MHz
    - Scandinavia: 400, 450 MHz (range!)
    - GSM: 25 MHz uplink + downlink, 200 kHz channels
- Generations:
  - 1G: analog
  - 2G: digital voice (GSM, CDMA)
  - 3G: digital data
  - 4G: LTE, MIMO, high bandwidth
  - 5G: higher frequencies (> 5 GHz), low latency

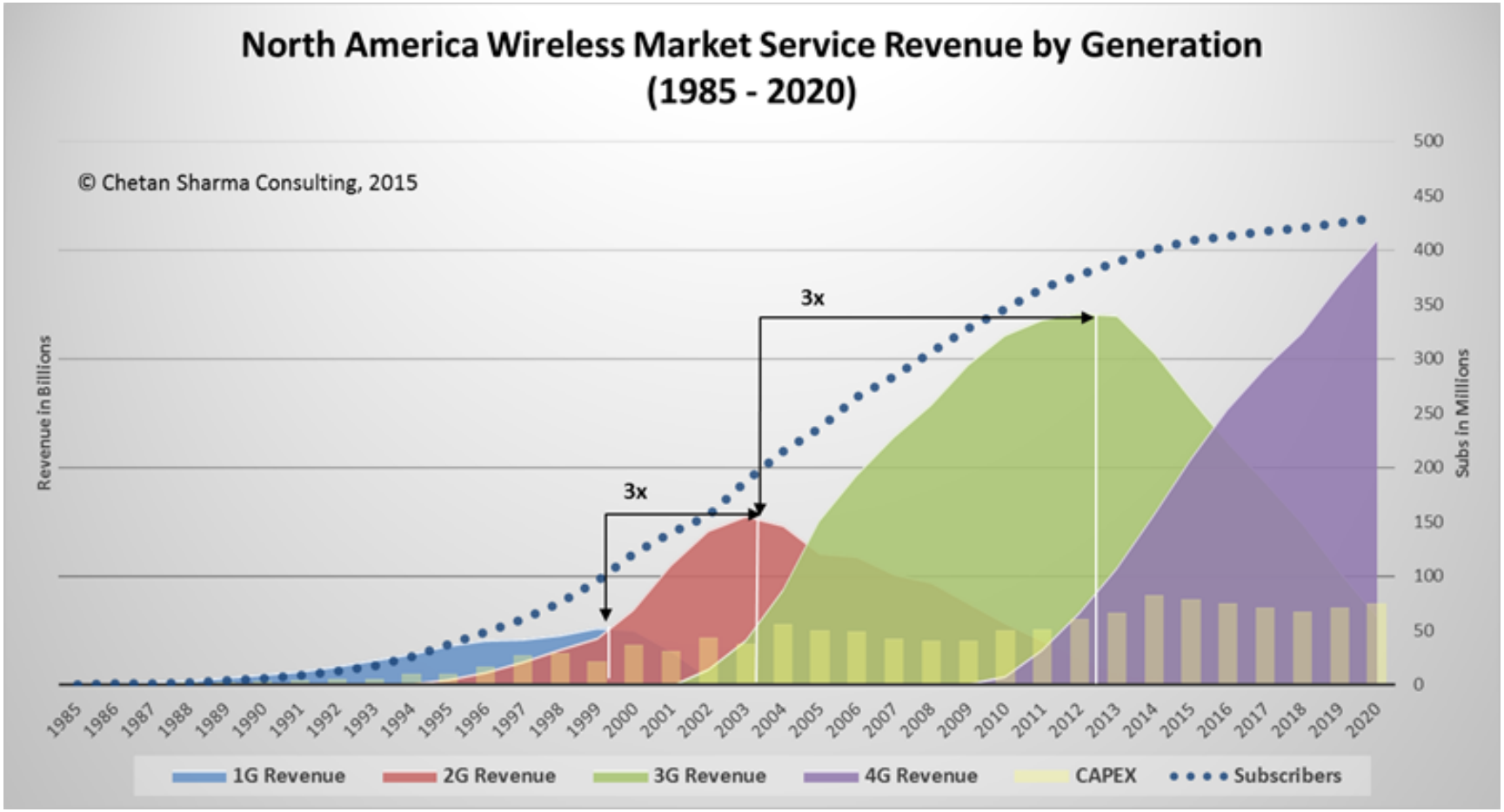
Evolution of Cellular Networks



Basic LTE architecture



Generations



Standardized QoS Characteristics

QCI: QoS Class Identifier

Classes vary by
- Bit rate guarantee
- Latency
- Packet loss probability

UE will typically have three bearers:
- Signalling QCI=5
- VoLTE QCI=1
- All other data QCI=9

Bearers may also have an "Allocation and Retention Priority" – priority level for establishing and retaining the bearer.

	Resource Type	Priority	Packet Delay Budget	Packet Error Loss Rate	Example Services
	guaranteed bit rate (GBR)	2	100 ms	10^{-2}	Conversational Voice
		4	150 ms	10^{-3}	Conversational Video (Li Streaming)
		5	300 ms	10^{-6}	Non-Conversational Vide (Buffered Streaming)
		3	50 ms	10^{-3}	Real Time Gaming
	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
		7	100 ms	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
		6	300 ms	10^{-6}	Video (Buffered Streamin
		8			TCP-based (e.g., www mail, chat, ftp, p2p file sharing, progressive video, etc.)
		9			

Wireless backhaul

- = BS → backbone network
  - one of the largest carrier OpEx components (30-40%)
- Traditional: T1 (1.5 Mb/s) - $600/month
- New solutions:
  - microwave
    - 800 Mb/s to 3 Gb/s (future)
  - CableCo fiber ($100/month/Mb/s)
  - bonded DSL
  - FiOS
  - Femtocells – in subscriber home