# Networking the Many, Tiny and Far Away

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# Early Challenges

- Moving information faster & farther than people
- Approaches
  - Put messages on faster beasts
  - Use light (e.g., smoke signals)
  - Use sound (e.g., drum signals)
  - Use water (e.g., hydraulic telegraph)
- Most of these have limited distances
  - And are point-to-point
  - Not always highly practical

Hydraulic Telegraph of Aeneas
4th Century BC, Greece

# The Chappe Telegraph

- France and beyond, ~1792 - 1846
  - Semaphores – 500 mph and 2-3msgs/min
  - Routers every 10-15miles / forming a **network**
  - Dependent on human operators
- Benefits
  - Message could reach <u>large distances</u> fairly quickly
  - Difficult to forge messages (message integrity)
- Impediments and challenges:
  - Good weather (visibility) required
  - Daylight required
  - Easy to intercept; “supported” steganography (!)
  - Not so mobile/tiny; expensive to run

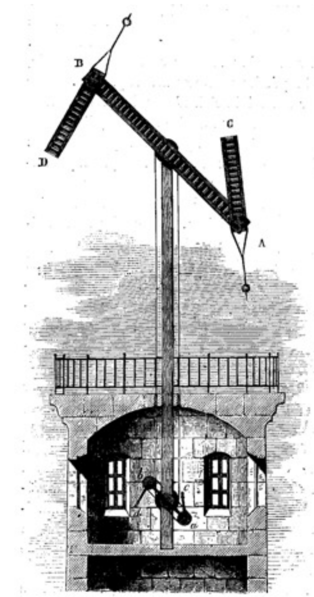
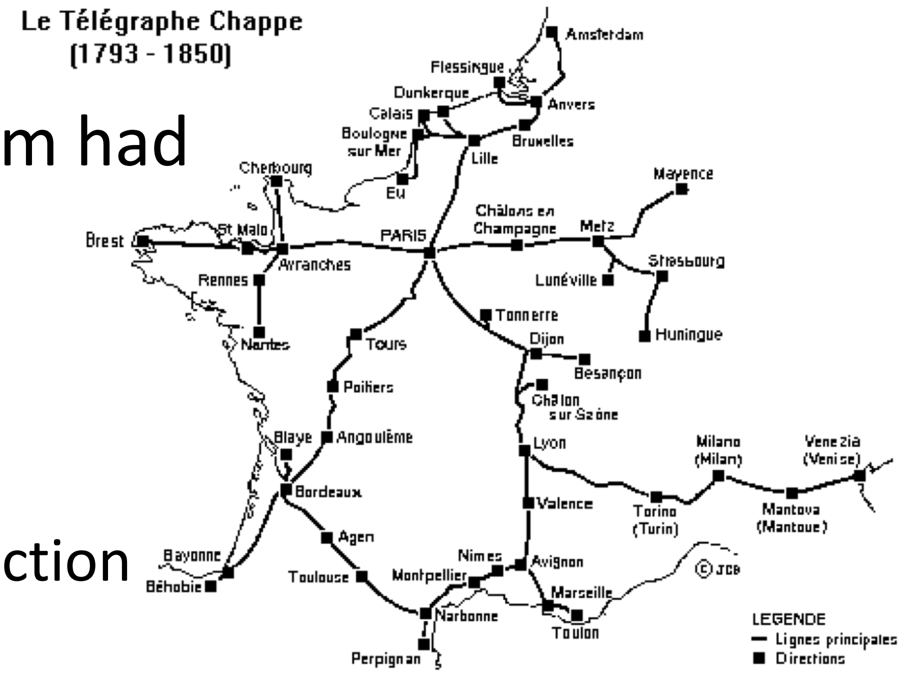


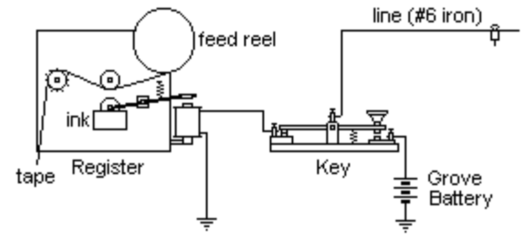

Fig. 19. — Télégraphe de Chappe.

# Chappe Telegraph (architecturally)



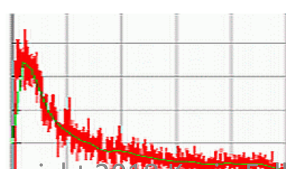

- Architecturally, this system had
  - Source coding
  - Control signals
  - Synchronization
  - Flow control
  - Error correction and detection
    - Selective ACK/repeat
- Some of these ideas appeared > 100 years earlier:
  - Robert Hooke, “On Showing a Way How to Communicate One's Mind at Great Distances”, 1684

# Electrical Telegraphy (1840+)




Typical Morse (Vail) Telegraph Station (1860s)

- Use electricity to send messages
- Basic components available by early 1800s
  - Volta's voltaic cell, galvanometer, and e-magnet
  - But the effect of electricity degraded significantly with <u>distance</u>
  - Joseph Henry solved this by 1830 but Morse didn't know (yet)
- Benefits
  - Cost reduction of perhaps 30x versus optical telegraphs
  - No weather or daylight or direct LoS issues; 24/7 operation
  - <u>Low latency</u> – (replaced pony express in US by Oct 1861)
  - Enormous <u>scale;</u> even a form of TDMA (Baudot) / msg switching
- Impediments:
  - Multiple wires in common conduit with degrading insulation
  - Confusion and suspicion
  - Repeaters



*Note: famous patent case 1854 – Morse v O'Reilly*

# Telegraphy and Cryptography

- Messages encoded first for compression (to save $)
- Codes for privacy (and compression) of telegrams
  - Use of codes differed significantly among countries
    - And many were business-specific (see talks by S. Bellovin)
  - In 1864, founding of ITU, standardized & allowed codes
  - In the US, earlier (1845) due to commercial use
- And…concern about the low latency as a threat
  - Routine information could now be sensitive
  - (e.g., ship departure records out before ship departs)

# The Telephone

- In 1875, Bell was working on the harmonic telegraph
  - Basically, FDM for multiple simultaneous telegraphy sessions
  - Ultimately he patents the telephone Mar 1876 (inventor?)
- Benefits
  - No operators required at endpoints
  - More rapid (15-20 wpm becomes more like 200 wpm)
  - No explicit per-message costs
- Challenges
  - Needs a circuit; quality of service over distance
  - Easy to intercept / harder to encode/cipher
  - Scale
    - Resource management of trunk lines ("operators")
    - Electromechanical switching

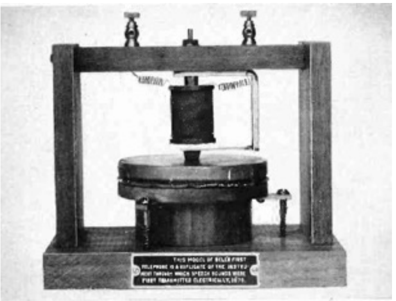


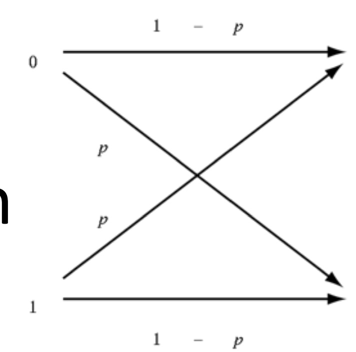
Photo: Jamie/Creative Commons

# The Telex Network

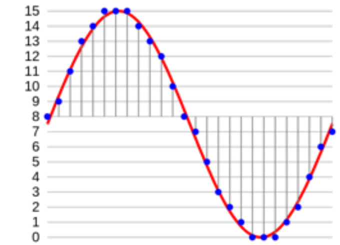
- Started in 30s, popular in post-WWII
- Special network for delivering messages among teleprinters – binary voltages ; not phone network
- First standardized worldwide network of its kind
  - 50 baud (~66 wpm)
- Transitioned to phone lines and modems
  - Ultimately replaced by FAX in 1980s (pictures!)
  - But still a hobby for some (“telex over Radio – RTTY”)
- Automated message switching (“InfoMaster”)
  - With machine-generated ACKs (unlike G2 FAX!)

# Understanding Channel Errors

- A formal mathematical understanding of communication channel impairments was lacking…
- Claude Shannon (1948)
  - Modeling of noise in an errant [bit changing] channel
  - A theory of information and entropy measure
  - Coining of the term 'binary digit' (bit)
- Really defined the limits of communication
  - And appropriate performance measures
  - Greatly affected thinking on cryptography



# The Digital PSTN




- Using ‘bits’ a possibility of ‘error-free’ long distance transmission became possible (Paper: “Philosophy of PCM”)
- Phone network evolution to digital core
  - Transition in the 1960s (tech: fiber optics, transistors)
  - Addressed problem of cumulative degradation in analog
  - Repeaters could re-construct the signal perfectly
    - Assuming sufficient S/N ratio, *reduces* noise
- Electronic switching replaces electromechanical
- ‘Last mile’ remained analog (still is in many places)

# Where Are We?

- Long distance – drums to optics to digital
- Scale – p2p links to global telephone network
- Reliability/resiliency – acknowledgements, retransmission, digital repeaters, coding
- Security – mostly codebooks and codewords

- So its about the 60s now.
  - And the many, tiny and far away … aren't always people

# Early M2M and Packet Networks

- The ARPANET – sharing resources using a network
  - An experiment in packet switching to provide resilience
  - Dynamic routing, statistical multiplexing (queues)
- X.25 and Minitel (1978 to 2012)
  - Packet switching supporting virtual circuits
  - Resiliency through re-routing; fixed window
  - Minitel – successful French personal services (social)


- The Internet – a ”concat”-ed network (“catenet”)
  - Short-term store and forward, packet format, gateways
  - Datagram service (no per-connection state) -> M2M!

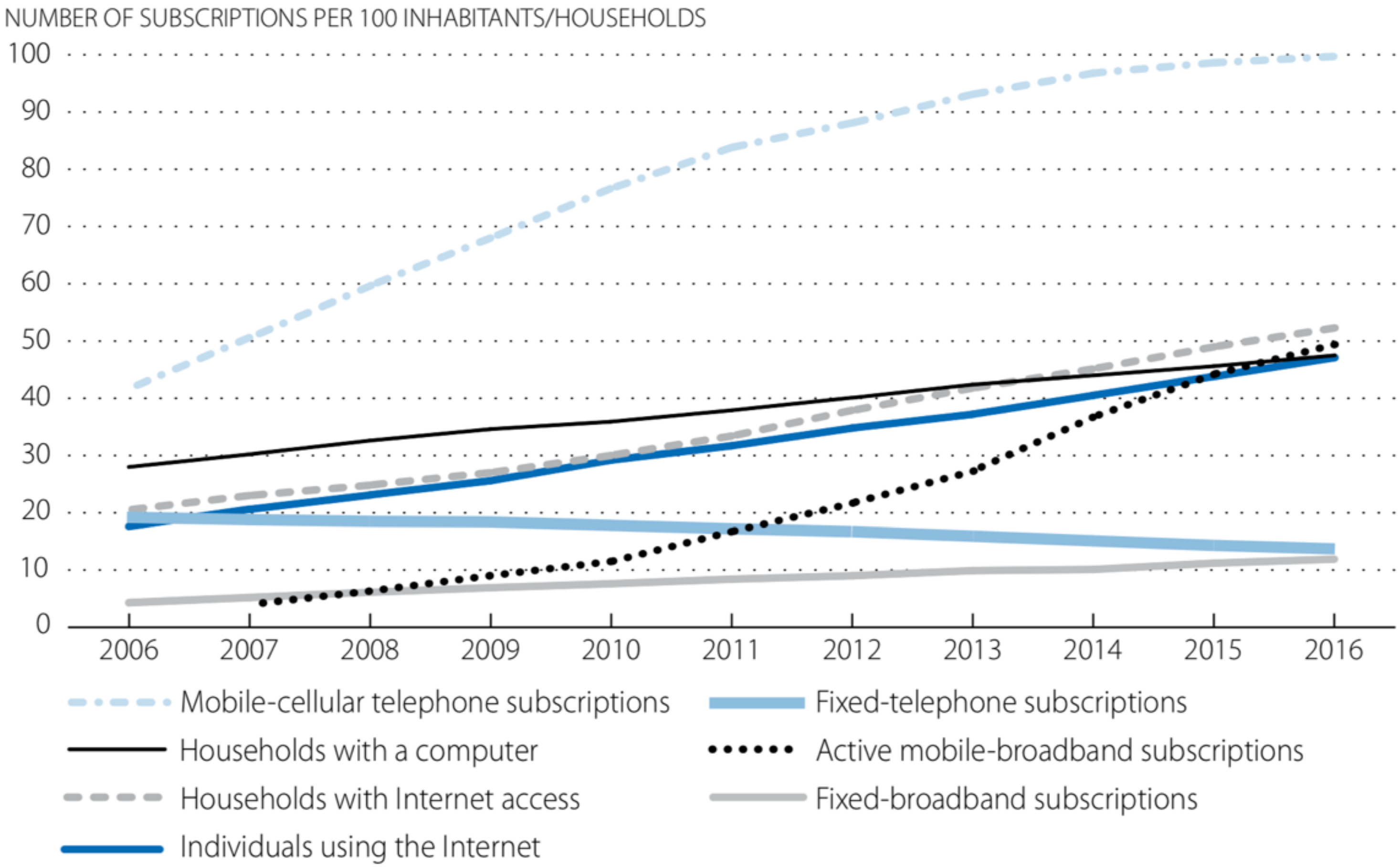
# The Many – Machines/People/Data

- Metcalfe's "law": net effect is $O(n^2)$
  - Validated with Tencent data (2015) [Zhang, Liu, Xu]
  - Supported Metcalfe's own Facebook analysis of 2013
- Changes in scale affecting networking pushed by
  - Internet growth – especially mobile / cellular
  - Hyperscale Data Centers – especially 'big data' and ML
  - Security & Social Networks – worldwide control & trust
  - IoT (maybe?) – are the predictions true?

# Cellular is for Mobile Internet

- Cellular started out to support voice calls
  - TDMA popular as a basis for channel allocation
  - "Crazy" idea of CDMA offered alternative
- By late 90s started to appreciate Internet (data)
  - And would adapt the network architecture appropriately
  - Many people could get cellular easier than fixed lines
- By 2008-2012 and 4G, there is no more debate
  - LTE changes to IP-based core with gateways (EPC)
  - 5G – use-case segmentation (M2M, broadband, IoT)

# And its still going…




*Note:* The figures for 2016 are ITU estimates.

*Source:* ITU (2016b), *Measuring the Information Society Report 2016.*

# Data Centers- Scale by Copying

- Roots in, yet quite different from, main frame DCs
  - Similar building, security, cooling, power, etc.
  - But DC is about <u>scale</u>: compute, storage, & networks
    - ("cattle not pets") -> avoid cumbersome specialization
- Individual hosts/computers do not really matter
  - So no need to own your own computers / DCs
  - And really, the same applies for networks
    - NFV (and SDN sort of) makes networks 'just an application'
    - That benefit from all the cloud/DevOps computing tools
- Related to 'serverless' (and maybe intent-based)

# DC Growth

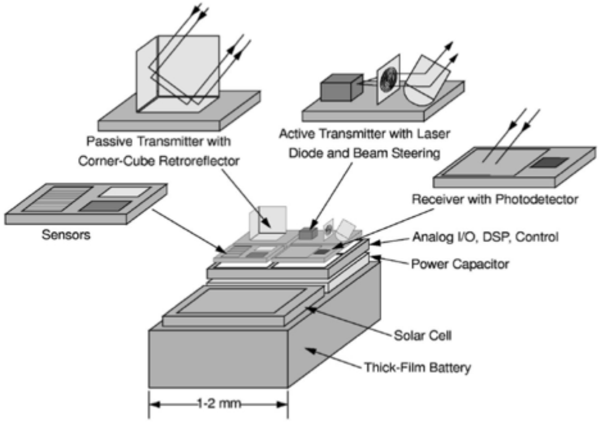

600
500
400
300
200
100
0
Public Cloud Data Center (28% CAGR)
Private Cloud Data Center (11% CAGR)
22% CAGR
2016-2021
Installed Workloads and Compute Instances in Millions
58%
42%
56%
44%
73%
27%
2016
2017
2018
2019
2020
2021
Source: Cisco Global Cloud Index, 2016–2021.

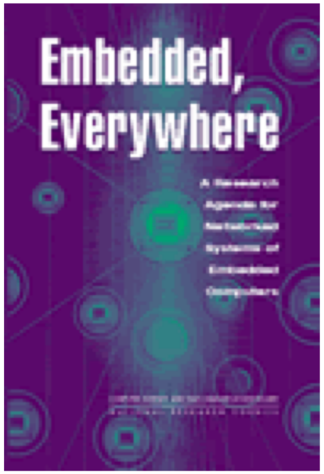
# Security & Social Networks

- Security traditionally the ‘CIA triad’ for a system
  - Confidentiality, integrity, availability
  - Accomplished with codes, retransmission, rerouting
- But the cryptographic foundations don’t fully help
  - Errors in implementation (software bugs/exploits)
  - Erroneous or misleading information content
- Solutions here stretch beyond networking/systems
  - Reputation systems and provenance
  - Social science and perhaps decision theory/game theory
    - Like we have with ‘behavioral economics’?

# The Tiny

- Early 2000's brought interest in wireless sensor networks: "smart dust" and "motes"
  - Focused on limited computing, power, and range
  - Clever inter-mote protocols and implementations
  - Progenitor of today's IoT (Internet of Things)
- 2001 NAP "Embedded Everywhere"

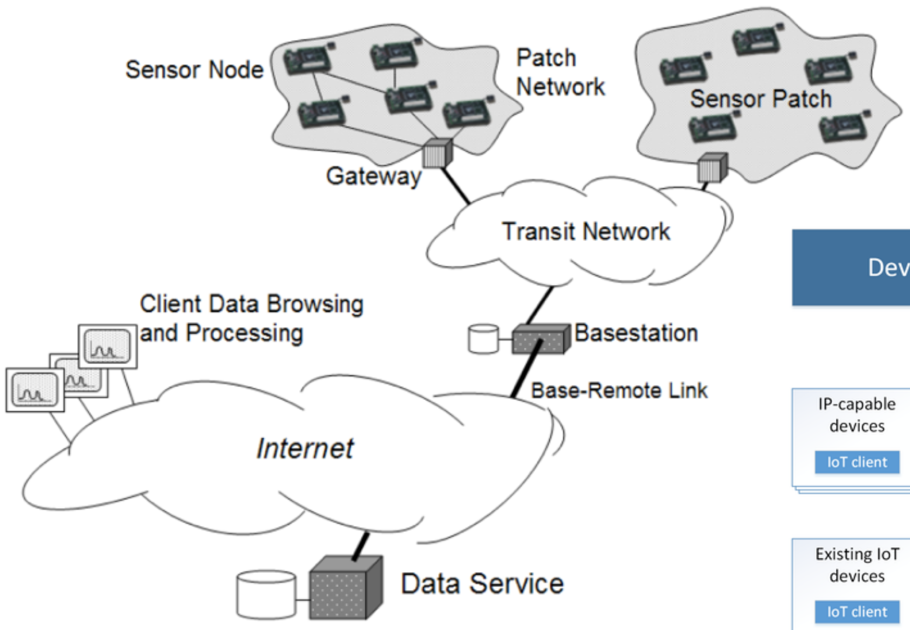


# IoT – Managing Tiny Machines

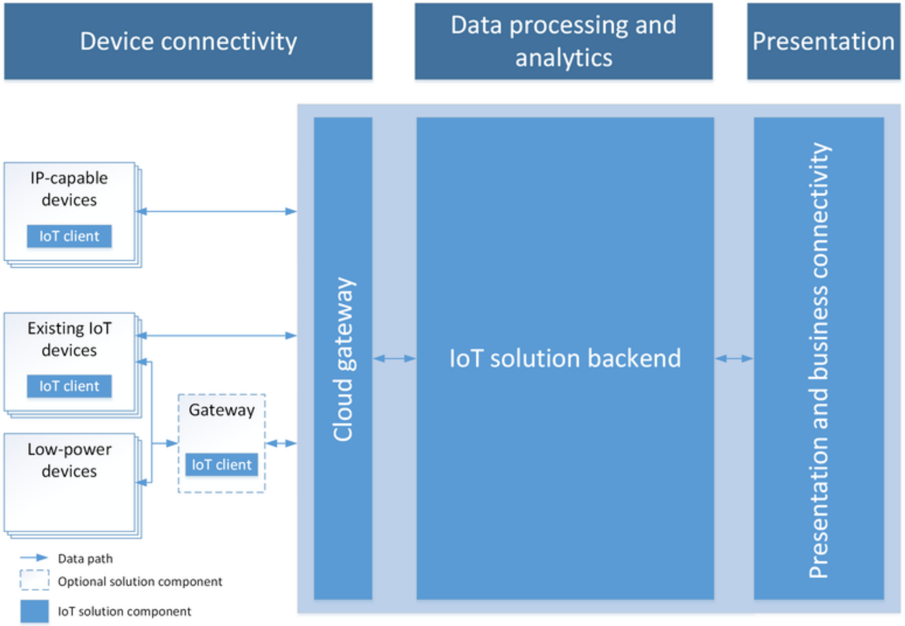
- Cloud frameworks to coordinate small devices
  - And a 'Function as a Service' model includes them
- Networking requirements
  - Local low-latency reactions (e.g., industrial)
  - Toleration of disconnected operation
  - Edge processing before cloud upload (e.g., in MEC)
  - Security and privacy of the data
    - Some data maybe never goes to the cloud
- Assumes better hardware than in 2001…
  - Basically, a Raspberry Pi+ (ARM, x86, 1GHz, Linux)

# The Canonical IoT Architecture




Intel Research 2002

Microsoft Azure 2018

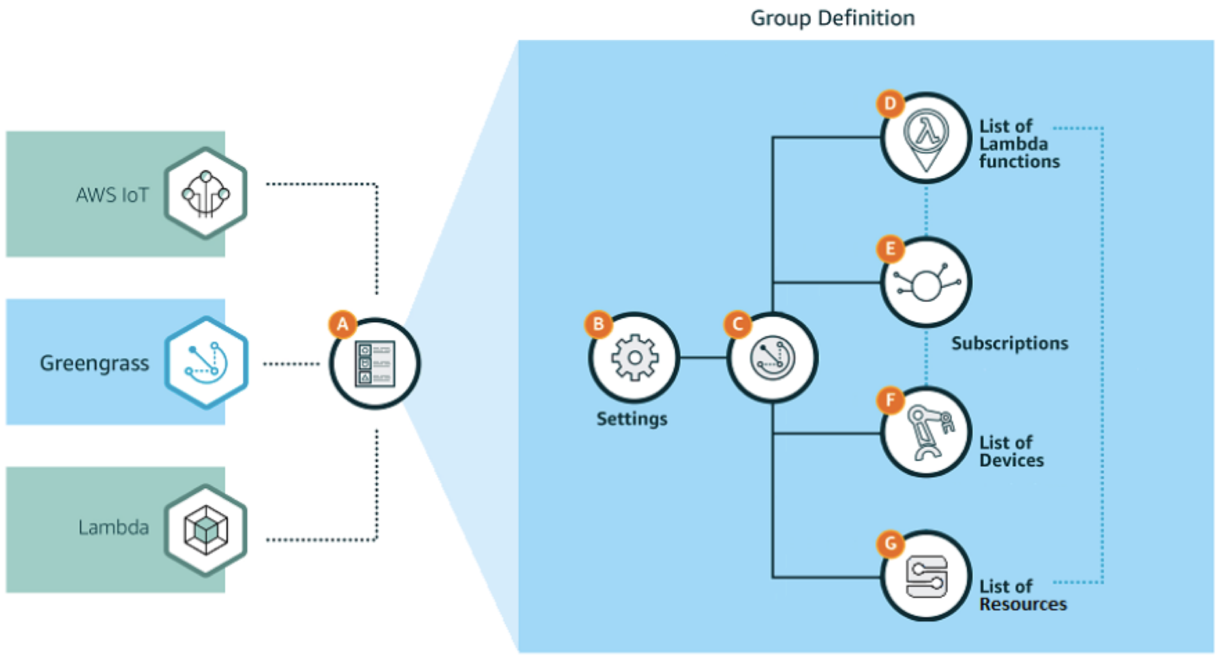


# LoRa and MQTT - IoT Protocols

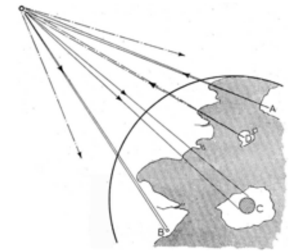
- When WiFi, LTE and 6LoWPAN don't quite cut it…
  - Well, 2G might, but its going, going, ….gone
- LoRaWAN – low-power wireless WAN tech
  - M2M, mile-long ranges, long endurance (decades)
  - Unlicensed spectrum
  - Strong restrictions on size, rate, uplink/downlink, etc.
- MQTT: M2M connectivity protocol (OASIS)
  - Simple pub/sub protocol on top of TCP/IP + TLS/SSL
  - Used with AWS, Azure, Google, Salesforce, IBM

# Example: Amazon Greengrass

- Programming & deployment extension of Amazon's IoT Core functions – networking + framework



# The Far Away: Space



Clarke – Fig 2

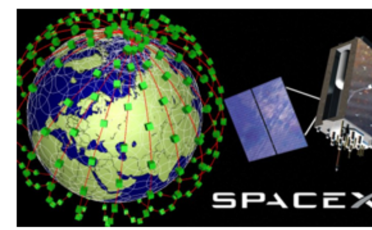
- Arthur C. Clarke – "Extra-Terrestrial Relays" – 1945
- Sputnik launched – 1957
- Project ECHO – 1960 – see movie 'The Big Bounce'
  - Goldstone, CA (genesis of NASA's DSN) to Holmdel NJ
  - Realizing a vision of John Pierce
- Telstar 1 – 1962 – telephone and video

ECHO I

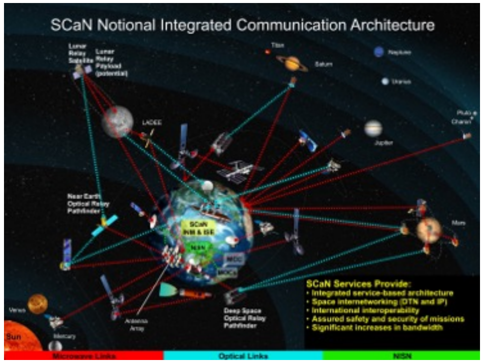

Telstar I

# Satellite Data Networks

- Much satellite communication is 'bent pipe'
- Modern: LEOs or MEOs, some with cross-links
    - Smaller satellites, polar orbits, lower latency
    - Providing Internet delivery (not TV or phone)




- SpaceX's Starlink
    - Ambitious 12,000 satellite network – 200mi/700mi up
    - Optical cross-connects; beam-formed antenna links
- OneWEb
    - 882 satellites, *not* using crosslinks (regulations)




# Far Out…. literally

- Beyond cislunar space, node density is low
- So, ‘networking’ has a different flavor
    - Very long latencies ; very limited comms assets
    - End-to-end retransmission not very practical
    - Bandwidth asymmetry may be extreme
    - Mobility may be highly predictable
    - Security (esp. integrity and availability) critical
    - Power – limited (solar) or not-so-limited (RTGs)
- DTN architecture addresses these issues and more

# Observations

- Original challenges were simply communicating over distances (fires, drums, Chappe telegraph)
- Next were about latency and secrecy
- Then about scale and availability
  - And networking entered the modern software era
- Now biggest concerns are largely about content
  - Analysis and interference / ML
  - Security, privacy, “fakeness” of data

# Thanks

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