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 10-15 miles / forming a network
  - Dependent on human operators

- Benefits
  - Message could reach large distances 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
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+)

- 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 distance
  - 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
  - Low latency – (replaced pony express in US by Oct 1861)
  - Enormous scale; 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
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...

NUMBER OF SUBSCRIPTIONS PER 100 INHABITANTS/HOUSEHOLDS

Note: The figures for 2016 are ITU estimates.
Data Centers- Scale by Copying

• Roots in, yet quite different from, main frame DCs
  • Similar building, security, cooling, power, etc.
  • But DC is about *scale*: 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

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)
  • Tolerance 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
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

• 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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