The Internet of The Future
(Personal View)

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Outline

- Current Internet
  - History
  - Philosophy
  - Design Principles
  - Non-linearity, Coupling, Layering
- Future Internet
  - End Devices
  - Traffic Growth
  - Key Technologies and Applications
  - Security, QoS
  - Philosophy
  - Expected Capabilities

Internet

- A world-wide broadcasting capability, an infrastructure for information dissemination, and a medium for collaboration and interaction among individuals and their computers/machines without regard for geographic location.
- Its influence reaches not only to the technical fields of computer communications but throughout society.
- Often called the National or Global or Galactic Information Infrastructure.

Internet (cont.)

- First implementation in 1965.
- Commercial Internet service providers (ISPs) began to emerge in the very late 1980s.
- The Advanced Research Projects Agency Network (ARPANET) was decommissioned in 1990.
- IP based
- Best Effort
- Enriched human life and key tool of globalization
- Platform for Freedom of Expression
- Different Paradigm for Individual Privacy
- Security is a concern

Internet Service Providers

- **10000-59000 ISPs worldwide**
- **7,000 Internet Service Providers (ISPs) in the US according to the CIA**
- **Best Internet Providers of 2018 (Reviews.com-July 2018)**
  - **Verizon**
  - **AT*T**
  - **HughesNet**
  - **Frontier**
  - **Spectrum (Charter)**

References

- *Barry M. Leiner, Vinton G. Cerf, David D. Clark, Robert E. Kahn, Leonard Kleinrock, Daniel C. Lynch, Jon Postel, Larry G. Roberts, Stephen Wolff', "**A Brief History of Internet",** February 2001.*
- *RFC1958 by IAB , "**Architectural Principles of the Internet**", June 1996*
- *RFC3439 by R.Bush and D. Meyer, "**Some Internet Architectural Guidelines and Philosophy**", December 2002.*

History

- In 1962, J.C.R. Licklider of MIT, who was the head computer research program at Defense Advanced Research Projects Agency (DARPA), wrote a series of memos in discussing his “Galactic Network” concept. He envisioned a globally interconnected set of computers through which everyone could quickly access data and programs from any site.
- Leonard Kleinrock at MIT published the first paper on packet switching theory in July 1961 and the first book on the subject in 1964, explaining the theoretical feasibility of communications using packets rather than circuits.

First Experiment

- **In 1965, working with Thomas Merrill, Lawrence G. Roberts, who is called the father of Advanced Research Projects Agency Network (ARPANET), connected the TX-2 computer in Massachusetts to the Q-32 computer in California with a low speed dial-up telephone line creating the first wide-area computer network ever built in U.S. Department of Defense Advanced Research Projects Agency (DARPA).**
  - **Realization that the time-shared computers could work well together, running programs and retrieving data as necessary on the remote machine, but that the circuit switched telephone system was totally inadequate for the job.**
- **In late 1966 Roberts went to DARPA to develop the computer network concept and quickly put together his plan for ARPANET, publishing it in 1967.**

Philosophy

- Connectivity is more valuable than any individual application such as mail or the World-Wide Web.
- The goal is connectivity, the tool is the Internet Protocol, and the intelligence is end to end rather than hidden in the network.
- In an ideal situation there should be one, and only one, protocol at the Internet level.
- End-to-end protocol design does not rely on maintaining state info in th network.
- States are maintained at the end points.
- Simplicity
- Scalability

Protocol Independence

- The Internet level protocol must be independent of the hardware medium and hardware addressing.
  - Allowing the Internet to exploit any new digital transmission technology of any kind, and to decouple its addressing mechanisms from the hardware.
  - Allowing the Internet to be the easy way to interconnect different transmission media, and to offer a single platform for a wide variety of Information Infrastructure applications and services.
- End-to-end functions can best be realized by end-to-end protocols.

Communications State Maintenance

- End-to-end protocol design should not rely on the maintenance of the end-to-end communication state inside the network. Such state should be maintained only in the endpoints, in such a way that the state can only be destroyed when the endpoint itself breaks.
- Complexity of the Internet belongs at the edges
- IP layer of the Internet should remain as simple as possible.
- The network's job is to transmit datagrams as efficiently and flexibly as possible.
- Nobody owns the Internet, there is no centralized control, and nobody can turn it off. Its evolution depends on rough consensus about technical proposals, and on running code.

Confidentiality and Authentication

- **Confidentiality and authentication are the responsibility of end users and must be implemented in the protocols used by the end users.**
- **Highly desirable that Internet carriers protect the privacy and authenticity of all traffic, but this is not a requirement of the architecture.**
- **Endpoints should not depend on the confidentiality or integrity of the carriers.**

General Design Principles

- All designs must scale readily to very many nodes per site and to many millions of sites.
- Performance and cost must be considered as well as functionality.
- Keep it simple.
- Modularity is good. If you can keep things separate, do so.
- Avoid options and parameters whenever possible. Any options and parameters should be configured or negotiated dynamically rather than manually.
- Be parsimonious with unsolicited packets, especially multicasts and broadcasts.

Network Complexity and Non-linearity

- Complexity impedes efficient scaling and increases in both capital expenditures (CAPEX) and operational expenditures (OPEX).
- Large networks exhibit, both in theory and in practice, architecture, design, and engineering (ADE) non-linearities which are not exhibited a smaller scale.
- Systems such as the Internet could be described as highly self-dissimilar, with extremely different scales and levels of abstraction.
- ADE non-linearity property is based upon two well-known principles fro non-linear systems theory
  - Amplification
  - Coupling

Amplification and Coupling

- **Amplification Principle states that there are non-linearities which occur at large scale which do not occur at small to medium scale.**
    - **In large systems, even small perturbations on the input to a process can destabilize the system's output.**
  - **Resonant phenomena are examples of non-linear behavior where small fluctuations may be amplified and have influences far exceeding their initial sizes**
- **Coupling Principle states that as things get larger, they often exhibit increased interdependence between components.**
  - **The more events that simultaneously occur, the larger the likelihood that two or more will interact. This phenomenon has also been termed "unforeseen feature interaction".**

Coupling and Synchronization

- Small amount of inter-connectivity causes the output of a routing mesh to be significantly more complex than its input.
- In the Internet domain, increased inter- connectivity results in more complex and often slower BGP routing convergence.
- In networking, horizontal coupling is exhibited between the same protocol layer, while vertical coupling occurs between layers.
- Coupling is intimately related to synchronization of various control loops, such as routing update synchronization and TCP Slow Start synchronization.
- Injecting randomness into these systems is one way to reduce coupling.

Layering

- **Layering or vertical integration has been applied to networking:**
  - **Error Control: The layer makes the "channel" more reliable (e.g., reliable transport layer).**
  - **Flow Control: The layer avoids flooding slower peer.**
  - **Fragmentation: Dividing large data chunks into smaller pieces, and subsequent reassembly (e.g., TCP MSS fragmentation/ reassembly).**
  - **Multiplexing: Allow several higher level sessions share single lower level connection.**
  - **Addressing/Naming: Locating and managing identifiers associated with entities.**

Layering and Efficiency

- **Layering has various conceptual and structuring advantages.**
- **In structured layering, the functions of each layer are carried out completely before the protocol data unit is passed to the next layer. This means that the optimization of each layer has to be done separately.**
  - **This is in conflict with efficient implementation of data manipulation functions. One could accuse the layered model (e.g., TCP/IP and ISO OSI) of causing this conflict.**
  - **Operations of multiplexing and segmentation both hide vital information that lower layers may need to optimize their performance**.

Violation of Simplicity

- Layer N may duplicate lower level functionality such as error recovery hop-by-hop versus end-to-end.
- Different layers may need the same information such as time stamp an packet sizing.
- Jitter rises from the design of the "middle" and "upper" layers that operate within the end systems and relays of multi-service networks.
- As a result of inter-layer dependencies, increased layering can quickly lead to violation of the Simplicity Principle.
- Horizontal (as opposed to vertical) separation may be more cost-effective and reliable in the long term.

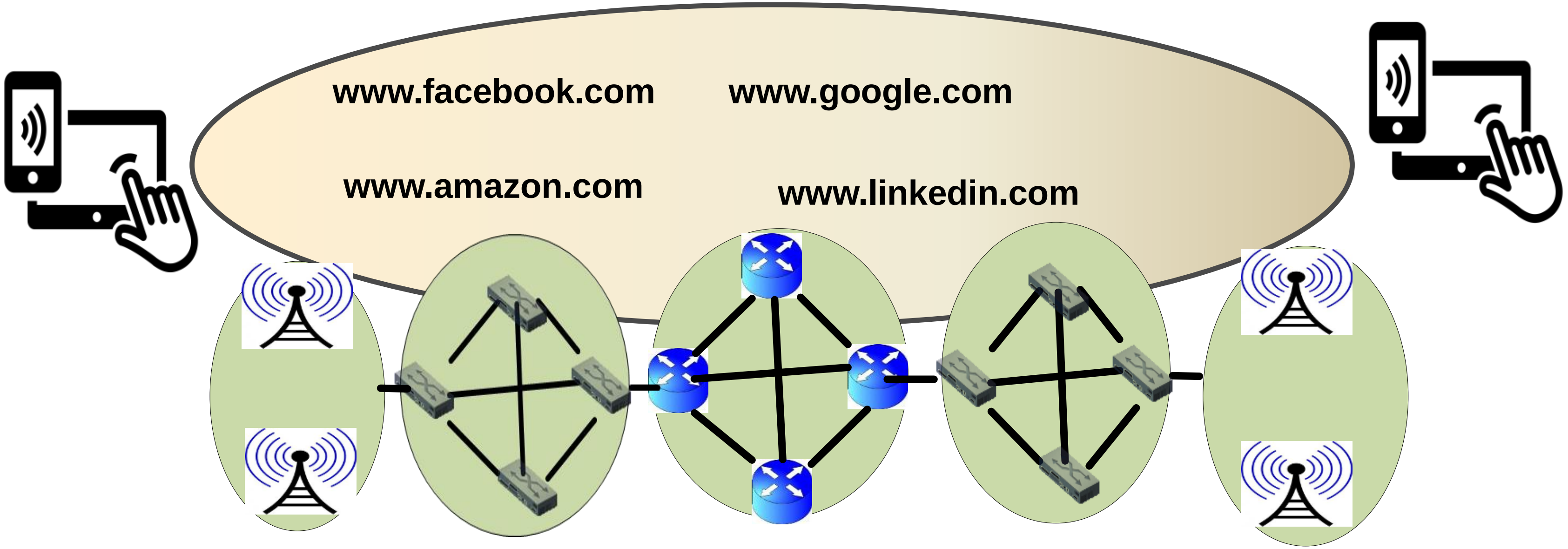
Optimization, Feature Richness and Control Plan

- Optimization provides tighter coupling between components and layers, and introduces complexity.
- While adding any new feature may be considered a gain, but increases system complexity.
- Interworking functions should be restricted to data plane interworking and encapsulations, and these functions should be carried out at the edge of the network
  - integrated solutions usually have poor performance.
  - There are more opportunities for failure in control plane interworking.

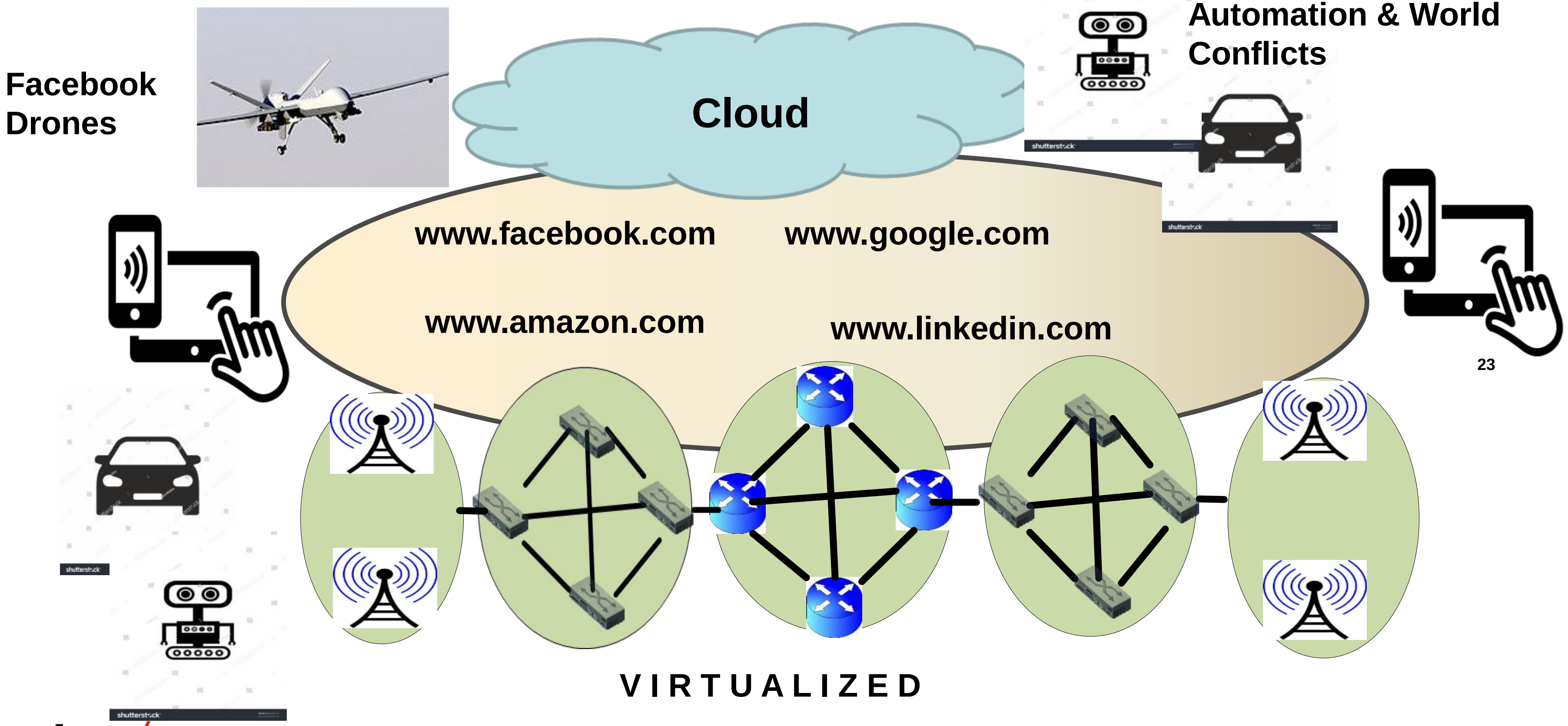
Future Internet!

We would be foolish to imagine that our vision is more than a snapshot of our current understanding.

Internet and End Devices



Future Internet and End Devices



Traffic Growth

- Nokia predicts that by 2022, total internet traffic will reach 330 exabytes per month. (That's 330 million terabytes).
- Cisco forecasts it will grow at 24 percent per year from a base of 96 exabytes per month in 2016 to 278 exabytes per month in 2021.
- Traffic growth will be driven by three things, according to Nokia:
  - Cloud services
  - 5G mobile networks, and
  - Internet of Things.
- In a recent report on securing IoT, Cisco predicted there will be 50 billion connected devices by 2020; Nokia reckons there will be 100 billion IoT devices by 2025, up from 12 billion in 2017
- World population is 7.6B in September 2018.

4G, 5G and 6G

- **4G which is at frequencies below a few gigahertz, provides generally available average downloads speeds at rates below 20Mbps.**
- **5G which is expected to support maximum peak download capacity of 20 Gbps**
  - **At Mobile World Congress 2017, Samsung showcased its 5G Home Routers, which achieved speeds of up to 4 Gbps**
- **5G's ultimate replacement -- terahertz-based 6G wireless -- which could be in commercial use within 10 years.**
  - **Support of 100 Gbps, using high frequencies in the range of 100GHz to 1THz**

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Core Technologies

- **Availability of a chip that can process up to 2.4 Tbps and a router line card of 12 Tbps have been claimed.**
- **Ethernet switches at 12.8 Tbps capacity with 300Gbps port speed is available.**
- **Massive parallel data transmission on 179 wavelength channels at a data rate of more than 50 Tbps has been demonstrated in 2017.**
- **Photonic (optical computing) to perform calculations at the speed of light (switching speeds of the order of 10^{-15} seconds)**
  - **Faster AI and ML decisions**
- **Google’s Jupiter fabric in a DC can provide more than 1 Pbps of total bidirectional bandwidth that is enough bandwidth for more than 100,000 servers to exchange data at 10 Gbps each.**

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Autonomous Driving/Cellular Vehicle-to-Everything (CV

- Autonomus Driving (where automated system takes full control of all driving tasks under all driving conditions that can be managed by a human driver)/CV2X requires
  - 2 Mbps bandwidth for uploading/downloading high resolution videos
  - Better coverage
  - Ultra reliability
  - Low Latency
    - To provide better safety, autonomous driving systems should be able to react faster than human drivers (600 msec), which suggests the latency for processing traffic condition should be within 100 ms

VR and AR

- **Virtual reality (VR) is an interactive computer-generated experience taking place within a simulated environment, that incorporates mainly auditory and visual, but also other types of sensory feedback like haptic (i.e. sensing forces applied to the patient).**
  - **Environment can be similar to the real world or can be fantastical, creating an experience that is not possible in ordinary physical reality.**
- **Augmented Reality (AR) systems may also be considered a form of VR that layers virtual information over a live camera feed into a headset/smartphone/tablet device giving the user the ability to view three-dimensional images**
  - **Applications of AR include video games, television, and personal navigation**

VR/AR and Telesurgery

- **VR/AR is known for leisure, but also used for Pain treatment, Neuropathy and Surgery.**
- **Telesurgery is the ability for a doctor to perform surgery on a patient even though they are not physically in the same location.**
  - **Doctor picks up a surgical instrument and cuts into somebody's flesh, doesn't use his/her own hands, and operates on patients that are hundreds of miles away.**

Characteristics of Future Internet

- Much more complex (more layering, more coupling, control plane interoperability,…) and Intelligent
  - Consequences of errors could be dramatic
- Subject to massive security attacks
- Expect to provide vital services
- No longer can be a just “Best Effort Network”

Coupling, Software Errors and Data Localization

- **1991 outage of AT&T's SS7 Due to Layer Coupling:** Outage was caused by software bugs in the switches' crash recovery code. In this case, one switch crashed due to a hardware glitch. When this switch came back up, it (plus a reasonably probable timing event) caused its neighbors to crash. When the neighboring switches came back up, they caused their neighbors to crash, and so on. The root cause turned out to be a misplaced 'break' statement.
- **Possible Error in Autocontrol Software could result in loss of lives.**
- **Risk of Internet fragmentation if countries wall off their own "internet" and/or require data localization**

Security

- IoT devices can be misused.
- Millions of connected cameras and home routers are being subverted in recent months and used to launch DDoS (distributed denial of service) attacks.
- Cisco expects the number of DDoS attacks to grow from around 1.25 million in 2016 to 3.1 million in 2021. Nokia expects 10 million such attacks in 2017 alone.
- The fast growth in Internet use and misuse does create security and routing challenges to overcome.

QoS for Telesurgery

- Latency: 150 msec (50 msec for haptic data)
- Jitter: <30 msec (2 msec for haptic data)
- Packet Loss: <1% (0.01% for haptic data)
- Average BW : 137Mbps-1.6Gbps (128 to 400 Kbps)
- Availability: <0.99999
- The packet loss in telesurgery is not as critical as in body area network, as it is the local anesthetist responsible for monitoring the physical vital signs. The remote surgeon mainly relies on the 3D video stream and haptic feedback.

QoS for Autocontrol, AR/VR

- **Latency (RTT): 5 msec (1-10 msecs)**
  - **Versus to 100msec mentioned before**
- **Jitter: <100microsecs**
- **Average BW: 3.36 Gbps**
- **Packet Loss: 1E-6**
- **Availability: <0.99999**

Manufacturing Robots/Plant Control

- **Latency (RTT): <10 -50 msec**
- **Jitter: <20 msec**
- **Average BW: 1-100 Mbps**
- **Packet Loss: < 1%**
- **Availability: 0.99999**

Future Internet Philosophy

- Respect Human Rights
  - Protection of Privacy and Data
  - User control of received, monitored, and publicized personal data
    - At End Points?
    - In Cloud?
    - In Core Network?
- Secure for social interactions and business transactions
- Intelligent and Globally seamless
- Should Internet have Moral Obligation?
- Free for people with income under certain levels set by governments

Future Internet Capabilities

- Accessible from anywhere in the world on the air and on the ground
- High Speed access at cities as well as at very remote locations/villages that can support VR/AR applications
- Application-aware QoS: QoS including bandwidth is allocated according to the application automatically
  - Bandwidth for Medical Emergency and Security applications must be available for all the time (i.e. network slicing)
- Protected and limited user data travels with the user
  - Data transfer among service providers (i.e. cloud SP, wireless SP, etc.)
- ML and AI, with AR/VR/Telepresence
  - to help the development of underdeveloped areas of the world
  - to stop human involvement in life threatening tasks

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Future Internet Technologies

- Support future applications
- Interoperate with current Internet technologies
- Expect to keep IPv6 addressing
- Simplified devices such as Ethernet Switches
- Simplified routing Protocols that are combined with ML/AI techniques, to reduce complexity and improve efficiency
- Support secure and intelligent Internet
- Seamless data transfer across borders

Thank you.

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