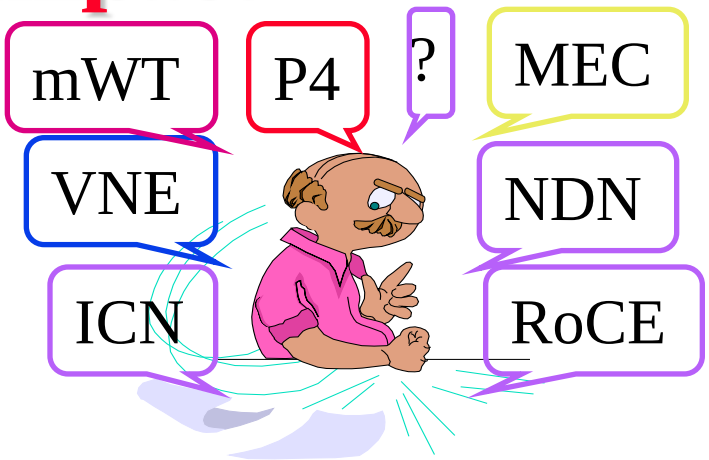
The Catch-up Game: Quest for the Impact



Raj Jain
Washington University in Saint Louis
Jain@wustl.edu

Keynote at ACM SIGCOMM 2017,
Los Angeles, CA, August 22, 2017.

These slides and recording of this talk are available at:
http://www.cse.wustl.edu/~jain/talks/sigcomm.htm

Overview

1. Is networking still hot or should I change?
2. Will the technology I am working on succeed?
3. Our initial research: Congestion control
4. Lessons Learnt: What is required to make an impact?
5. Current developments – A Limited personal view


Let's Make Networking
Great Again

Networking = "Plumbing"

- Networking is the "plumbing" of computing
- Almost all areas of computing are network-based.
  - Distributed computing
  - Big Data
  - Cloud Computing
  - Internet of Things
  - Smart Cities

- Networking is the backbone of computing.

Networking is already great!

Networking is Fueling All Sectors of Economy

- Networking companies are among the most valued companies: Apple, AT&T, Samsung, Verizon, Microsoft, China Mobile, Alphabet, Comcast, NTT, IBM, Intel, Cisco, Amazon, Facebook, …
  - Þ All tech companies that are hiring currently are networking companies
- Note: Apple became highly valued only after it switched from computing to communications (iPhone)

Networking = Economic Indicator

Smart Everything

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

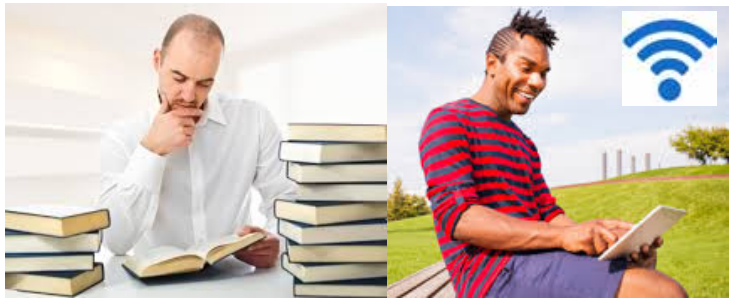
Smart Space

Smart Industries

Smart Cities

What's Smart?

- Old: Smart = Can think Þ Computation
  = Can Recall Þ Storage
- Now: Smart = Can find quickly, Can Delegate
  Þ Communicate = Networking
- Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, …



Not-Smart Smart

Networked Þ Smart

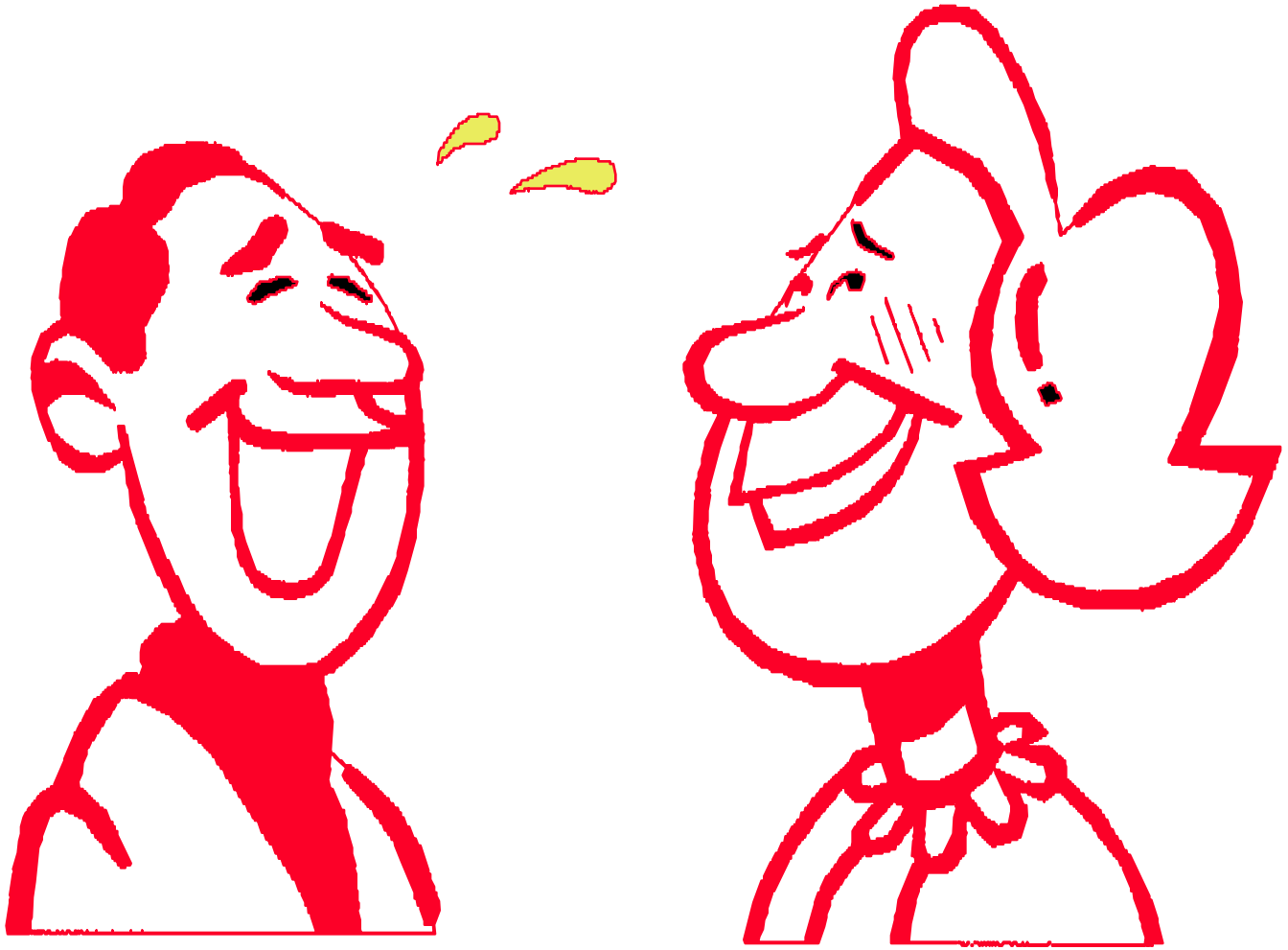
Am I in the Right Field to Impact?

- YES, Networking is hot!

2. Will the technology I am working on succeed or fail?

History is written by the victors - Winston Churchill

Before



After

Networking: Failures vs Successes

- 1980: Broadband Ethernet 10Broad36 (vs. baseband)
- 1984: ISDN (vs. Modems)
- 1986: MAP/TOP or Token Bus (vs Ethernet)
- 1988: OSI (vs. TCP/IP)
- 1991: DQDB
- 1992: XTP (vs. TCP)
- 1994: CMIP (vs. SNMP)
- 1995: FDDI (vs. Ethernet)
- 1996: 100BASE-VG or AnyLan (vs. Ethernet)
- 1997: ATM to Desktop (vs. Ethernet)
- 1998: ATM Switches (vs. IP routers)
- 1998: MPOA (vs. MPLS)
- 1999: Token Rings (vs. Ethernet)
- 2003: HomeRF (vs. WiFi)
- 2007: Resilient Packet Ring (vs. Carrier Ethernet)
- QoS, Mobile IP, IP Multicast, IntServ, DiffServ, …

Technology alone does not mean success.

Requirements for Technology Success

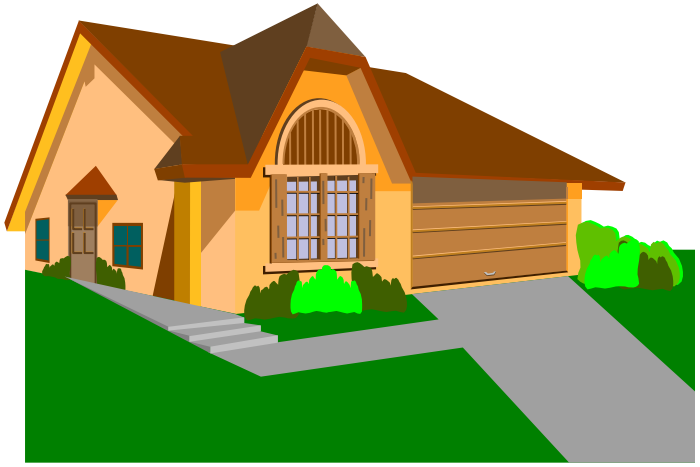
1. Low Cost: Low startup cost Þ Evolution
   Þ Each customer must save.
   2x cost Þ 10x performance
2. Killer Application (Video on demand)
3. Coexistence with legacy (Ethernet)
   Existing infrastructure is more important than new technology Þ Even legacy name is important (FDDI vs. 100M Ethernet)
4. Timely completion (OSI)
5. Promised Performance (FDDI)
6. Manageability
7. Interoperability

IPv6

- 1993-1994: IPng, 1995: RFC2710 – 1st RFC w IPv6
- Requirements for Success
  1. ~~Low Cost~~: Dual Stack
     Critical for mass technology
  2. ~~Killer Applications~~
  3. ~~Coexistence with legacy networks~~
  4. Timely completion
  5. Promised Performance?
  6. Manageability
  7. Interoperability

Transition strategy is very important

Old House vs. New House



- New needs:
  Solution 1: Fix the old house
  Solution 2: Buy a new house
  Changing millions of houses is difficult.

Given the current state of networking, clean slate is difficult

Impact Question 2: Will My Technology Succeed?

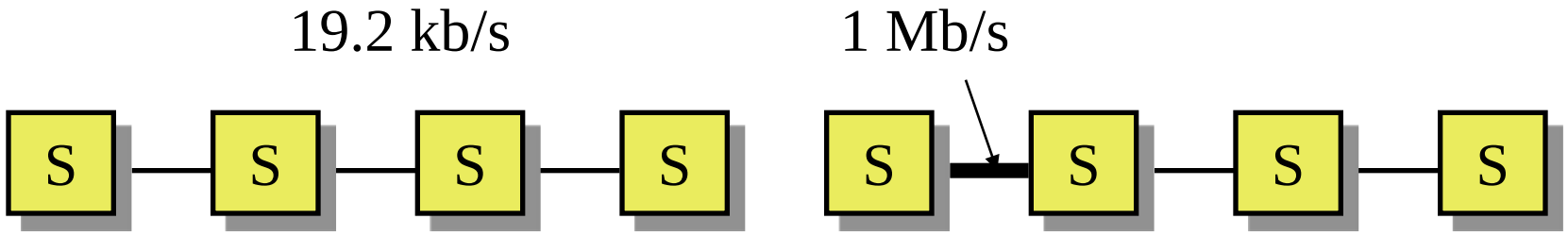
- Lower cost or killer application, and transition strategy are key

3. Our Research on Congestion Control (37 years ago)

Study the past if you would define the future - Confucius

Our Congestion Research

- 1979-1980: High-Speed Network = 10Mbps Ethernet



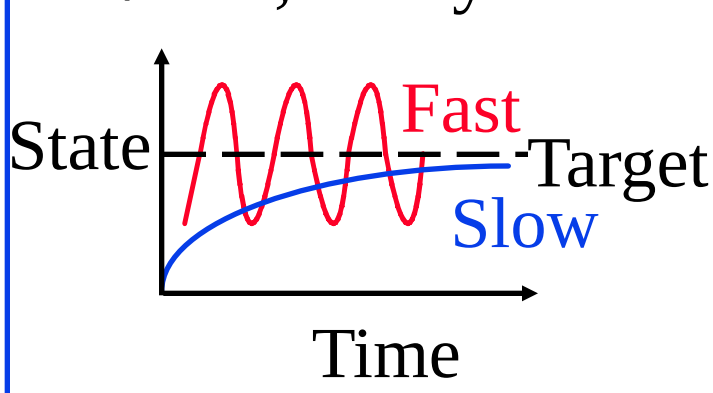
File transfer time = 5 minutes Time = 7 hours

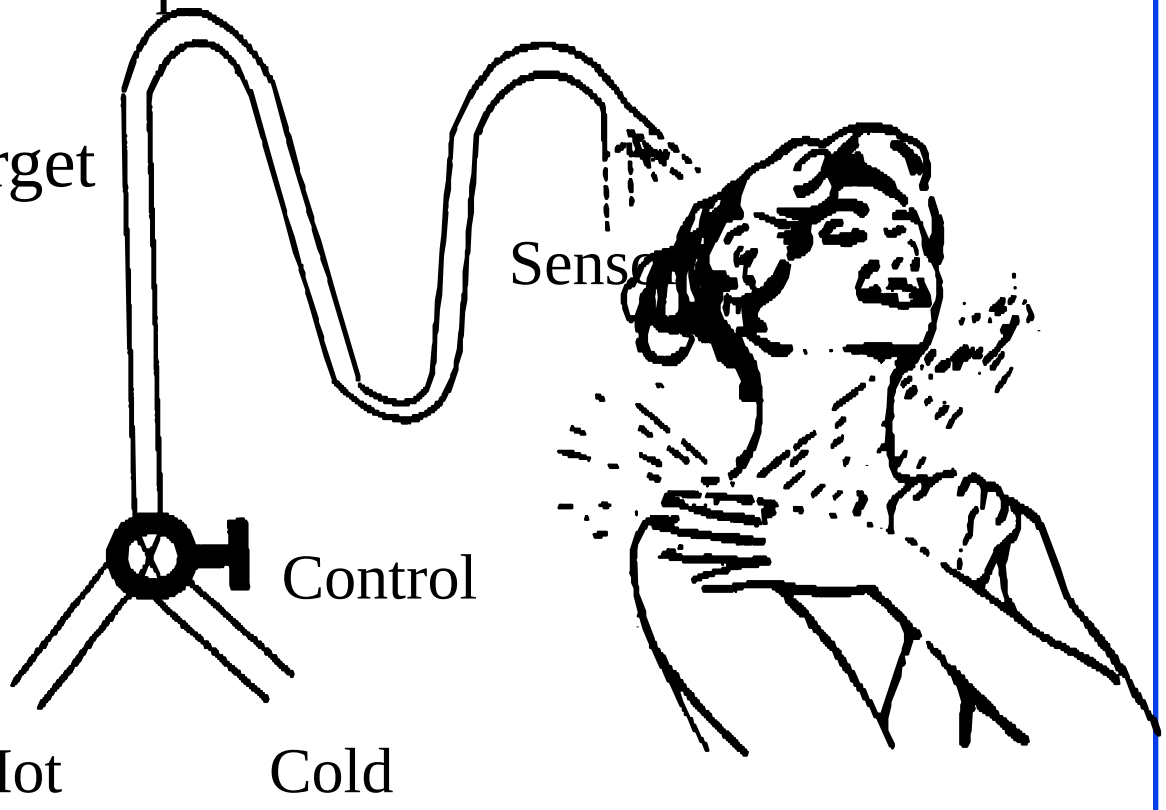
- Collaborators: KK Ramakrishnan, DM Chiu, Bill Hawe
- 1. Implicit Indication: Delay Based – Too noisy
- 2. Explicit Congestion Indication: DECBit
  - Question 1. What to do on a timeout?:
    Conventional Wisdom: Retransmit all packets
    Our Results: No, Drop the congestion window to 1

Ref: Raj Jain, "**A Timeout Based Congestion Control Scheme for Window Flow-Controlled Networks**," IEEE Journal of Selected Areas in Communications, Vol. SAC-4, No. 7, October 1986, pp. 1162-1167.

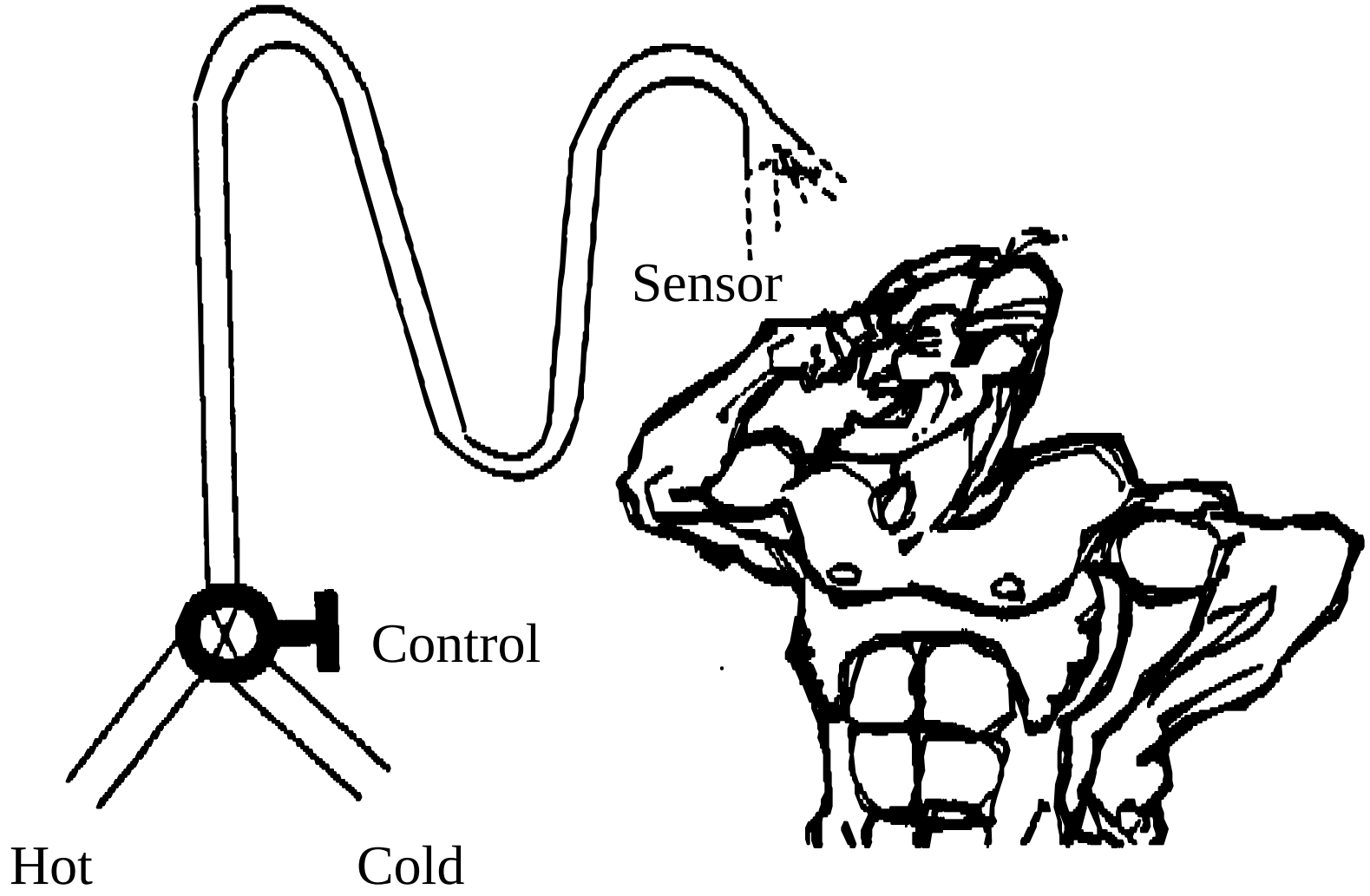
The Shower Experiment

- Question 2. How often to go up?
  - Conventional Wisdom: Every packet
  - No, Every round trip





The Shower Experiment



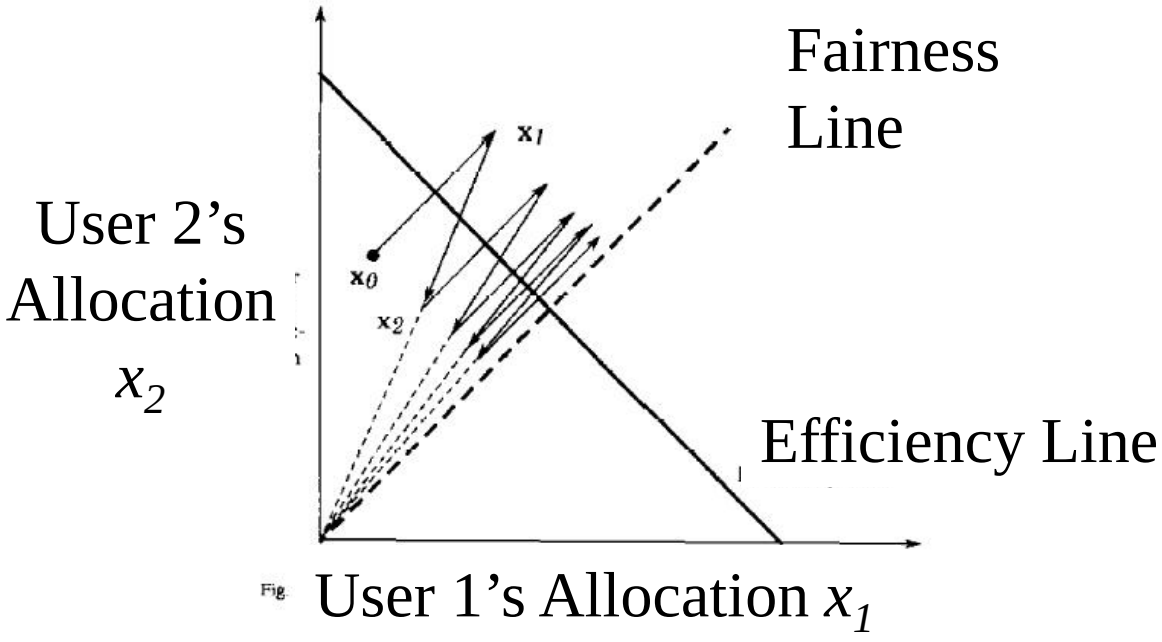
Fairness Index

- Question 3: What is a fair/efficient allocation?
- Requirements:
  - Scalable: Apply to n=2 users or n=2 million users
  - Easy to Interpret: Lie between 0 and 1 or 0 and 100%
  - Equal Allocation = 100%
  - If *k* of *n* receive *x* and *n*-*k* users receive zero throughput: the fairness index is *k*/*n*.

$$f(x_1, x_2, \ldots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n\sum_{i=1}^{n} x_i^2}$$

AIMD

- Question 4: How to achieve fairness and efficiency?
  - Solution: **A**dditive **I**ncrease, **M**ultiplicative **D**ecrease



Fig

Ref: D. Chiu and Raj Jain, "**Analysis of the Increase/Decrease Algorithms for Congestion Avoidance in Computer Networks**," Journal of Computer Networks and ISDN, Vol. 17, No. 1, June 1989, pp. 1-14, http://www.cse.wustl.edu/~jain/papers/cong_av.htm

Reasons for Impact

- This was leading edge research
  - There were 8 papers on congestion control in 1980
  - There are 160 papers in 2016 in IEEE Xplore
- The results were based on solid mathematical foundations, validated by simulations
- Tech Transfer: We found simple ways to explain our results to our management and to the world
  - Withstood the test of time, 37 years later

4. What is required to make an impact?

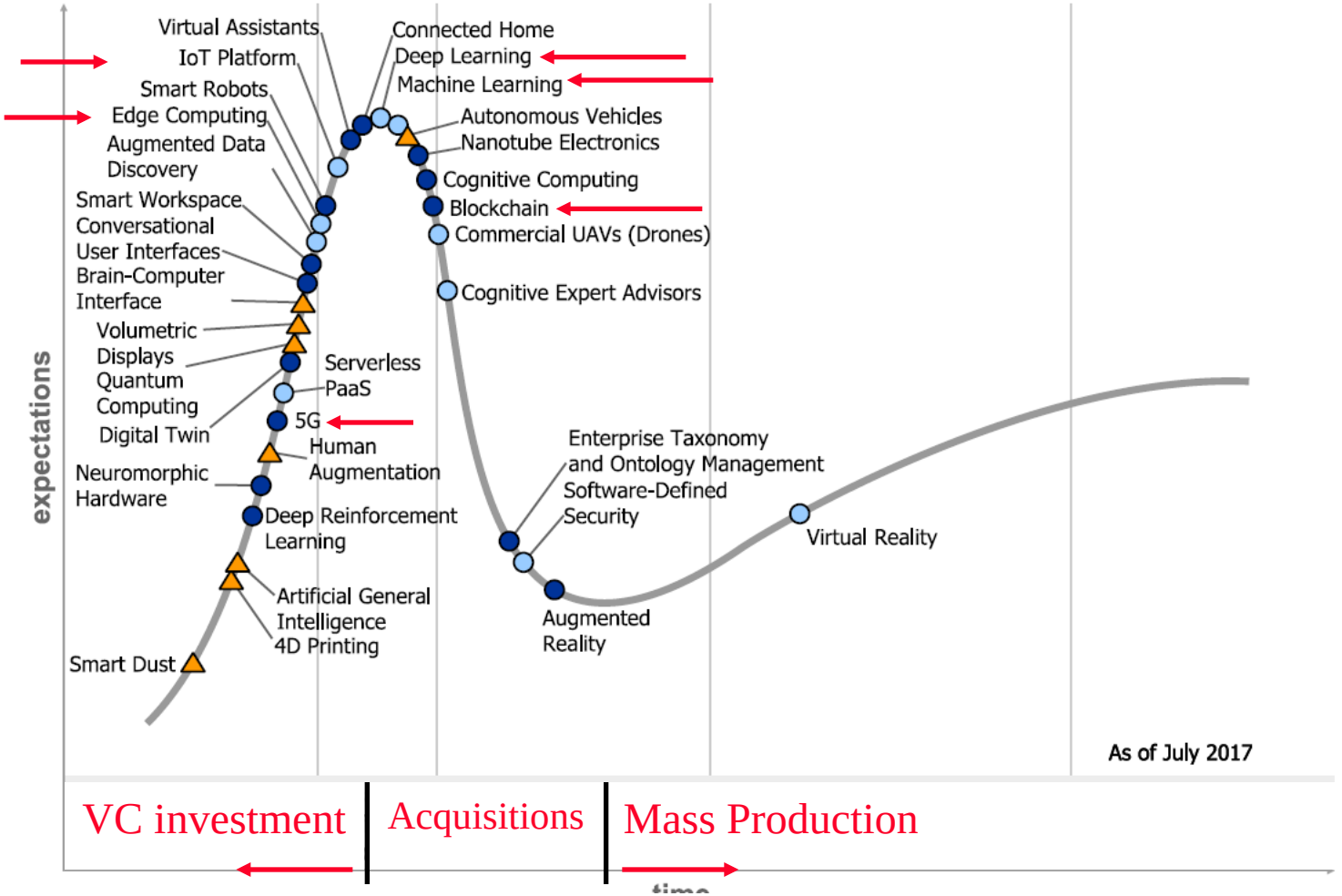
1. Select the Right Research Problem

1. Boss tells you (Applies to company employees)
2. Work on the same problem as last year/last decade
   - ø QoS: 35,613 papers in IEEE Xplore
     2,059 papers in 2016
3. NSF Calls for proposals
4. Be your own boss:
   1. Watch for paradigm shifts
   2. Hype cycles

Adapt to Paradigm Shifts

- 1975: Operating Systems
- 1980: Ethernet Design
- 1985: Congestion Control
- 1990: ATM Networks
- 2000: Optical Networks
- 2005: Wireless Networks
- 2010: Next Generation Internet/SDN
- 2013: Multi-Cloud Computing
- 2016: Security
- …

Gartner's Hype Cycle for Emerging Tech 2017



Ref: M. Walker, "Hype Cycle for Emerging Technologies 2017," Gartner Report G00314560, July 21, 2017.

2. Bring it to Completion

- Step 1: Analyze/develop new algorithm/idea
  - Make most of your time – don't throw it in dustbin
- Step 2: Publish
  - Required for the annual review. But don't stop here
- Step 3: Bring it to IETF/IEEE/ITU
  - ECN by K. K. Ramakrishnan and Sally Floyd
- Step 4: Implement and open source
  - Slow start by Van Jacobson
- Step 5: Productize
  - SDN (Nicira) by Casado, Mckeown, …

3. Every Person is a Company

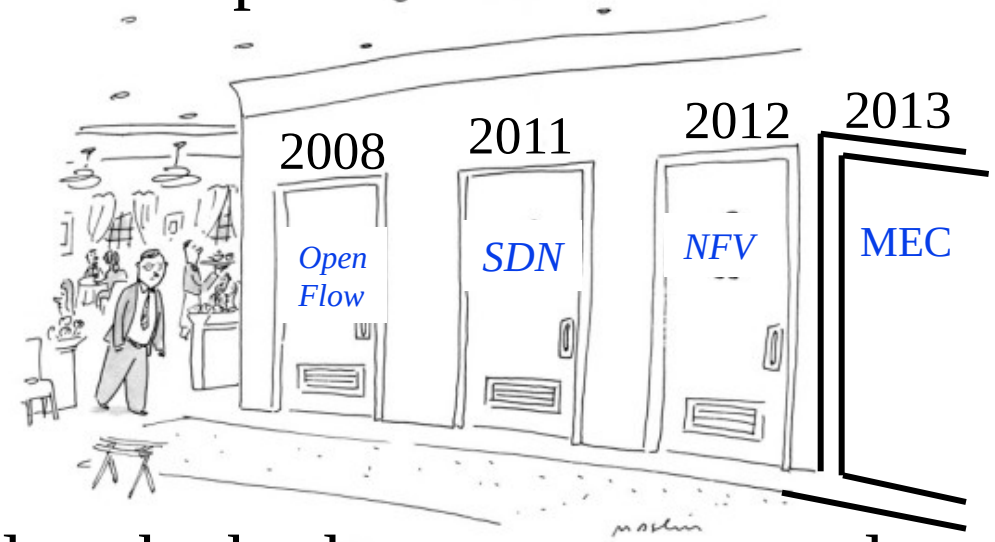
- Companies need:
  1. Product Idea
  2. Engineering
  3. Marketing
  4. Sales
- Measure success by adoption. Publication ≠ Sales
- Balance your research investment: Diversify
  - Long term 70%
  - Medium Term 20%
  - Short Term 10%
- **10-20-70 Formula**: 10% of R&D on distant future, 20% near future, 70% on today's products [Google]

4. Don't Be Let Down by a Failure

- Success is filled with failures.
  - 90% Rejection rate from NSF
  - 50% Rejection rate from Journals
    Rejections always result in improving the paper
- Think Positive: Good things may happen after bad ones
  - A company refused to extend funding ⇒ Nayna
  - A paper rejected does not mean the idea is bad
    - Fairness Index was rejected ⇒ 3560 citations
  - Good news may not be good in the long term

Academics: Challenges

- Need to get too deep in one area
  - Þ Can't move with fast changing world
- Time has shrunk. No topics remains hot for 5 years
  - ø PhD topics become out of date by the time a student completes the PhD



- Difficult to be both entrepreneur and academic

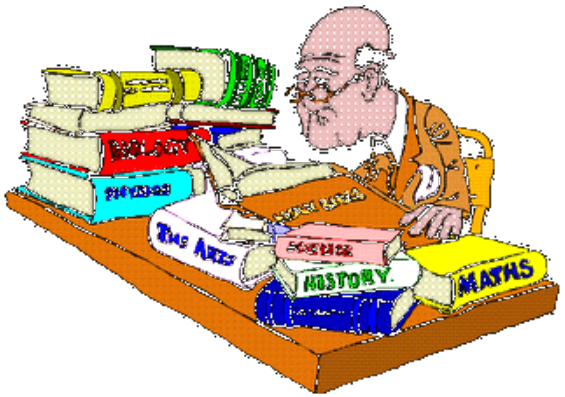
Entrepreneurs vs. Academics: Issues

Laxmi: Goddess of Wealth

Saraswati: Goddess of Knowledge

Different Belief Systems

Entrepreneur vs. Academics: Issues (Cont)



- Different Motivators: Money vs. publications
- Different Requirements: customers vs. citations
- Different Languages: English vs. Greek l , m
- Different Playgrounds: Business vs. Technical Conf.
- Different Time Scales: Short-term vs. Long Term

Summary:
What is Required to Make an Impact?

1. Every person is a company
2. Select the right problem
3. Bring it to completion = Adoption

5. Recent Research Topics

1. Multi-Cloud Computing
2. IoT/Smart Cities
3. Security
4. Blockchains

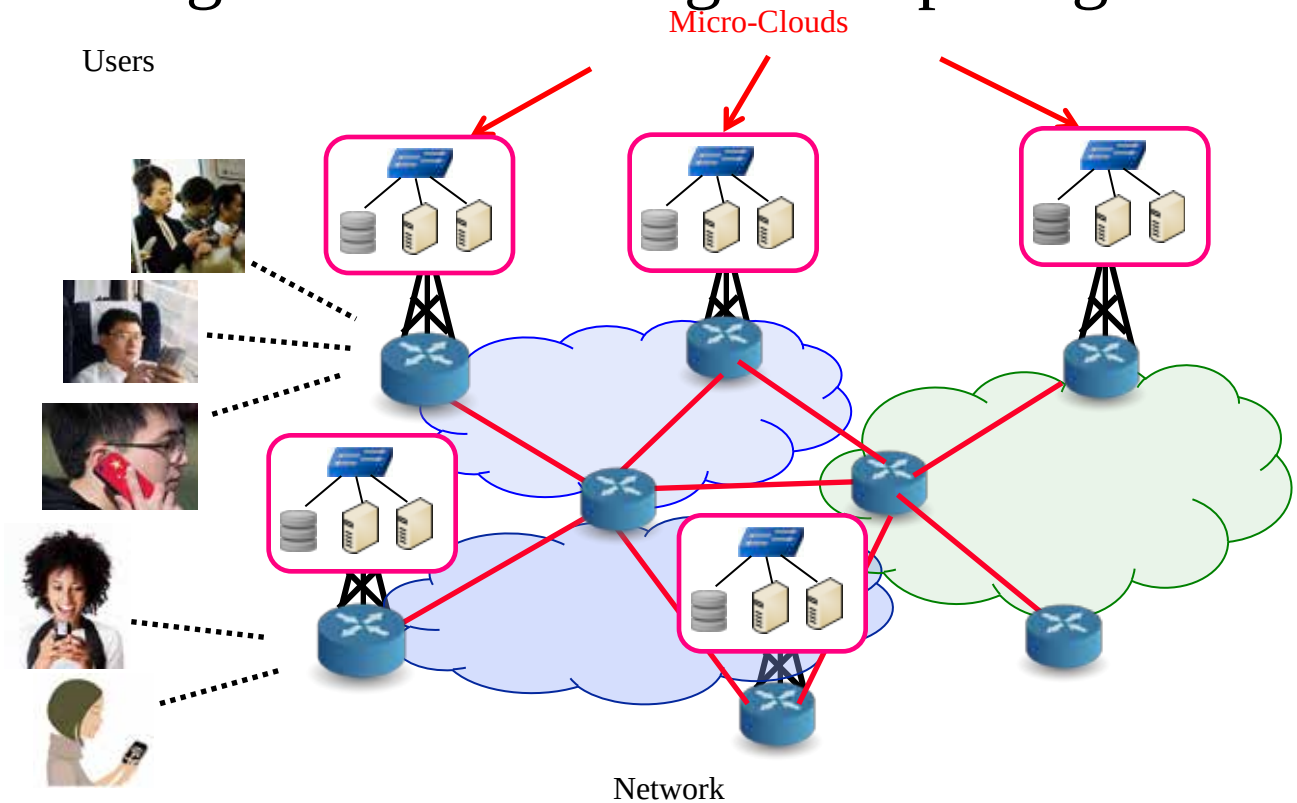
Not an exhaustive list. Just personal areas of research.

Trend: Micro-Cloud Computing

- Cloud service started in 2006
- Then: Cloud = Large Data Center. Multiple VMs managed by a cloud management system (OpenStack)
- Today: Cloud = Computing using virtual resources
  - mCloud = Cloud in a server with multiple VMs managed by OpenStack

Trend: Mobile Edge Computing

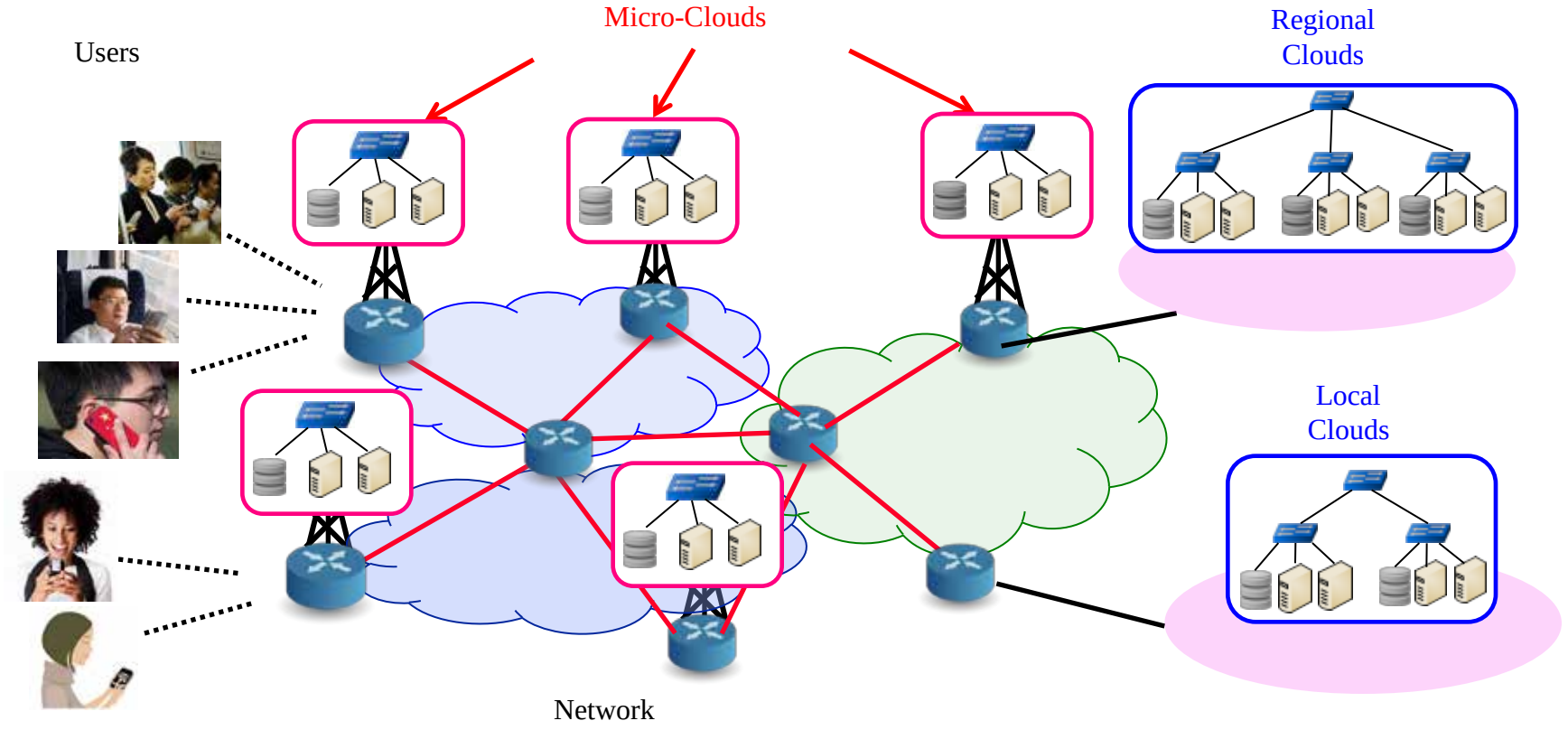
- To service mobile users/IoT, the computation needs to come to edge Þ Mobile Edge Computing



Ref: Lav Gupta, Raj Jain, H. Anthony Chan, "Mobile Edge Computing - an important ingredient of 5G Networks," IEEE Softwarization Newsletter, March 2016, http://www.cse.wustl.edu/~jain/papers/mec16.htm

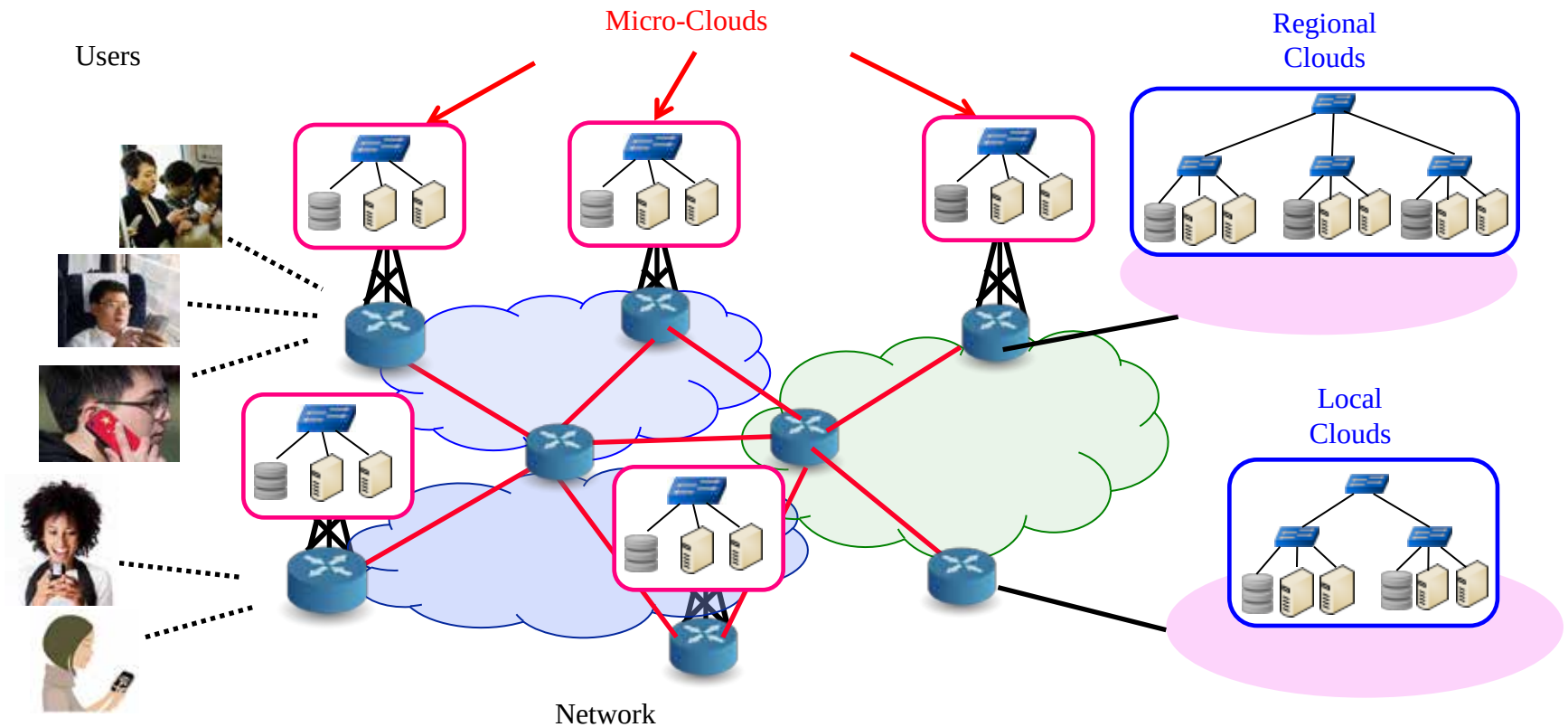
Trend: Micro-Services

- All major applications, such as, Facebook, Netflix, etc. consist of a number of micro-services instantiated on demand on virtual machines at multiple locations



Multi-Cloud Hierarchy

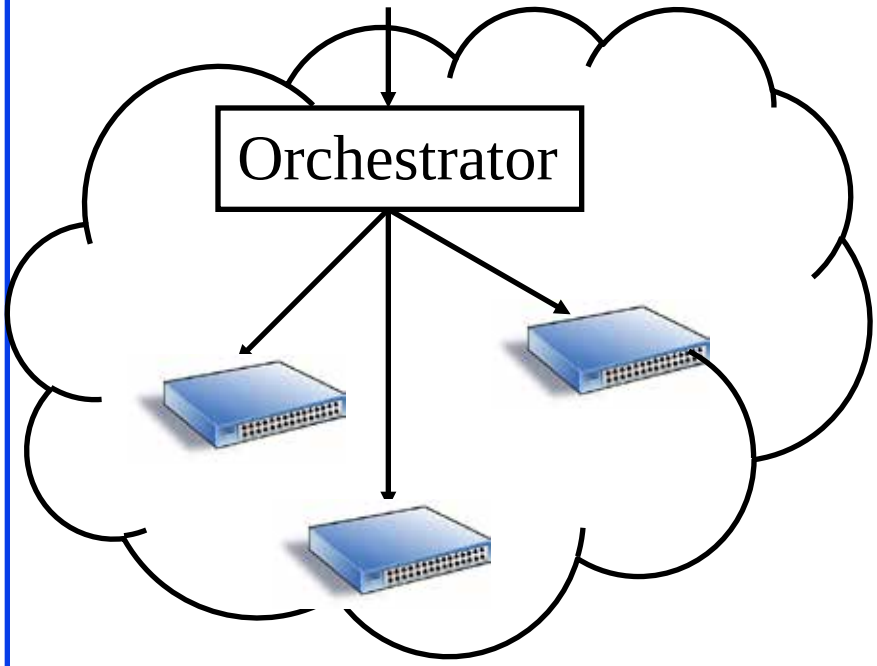
- Wide area clouds, local area clouds (home routers with cloud features), Personal area clouds (cars), body area clouds (smart phone)



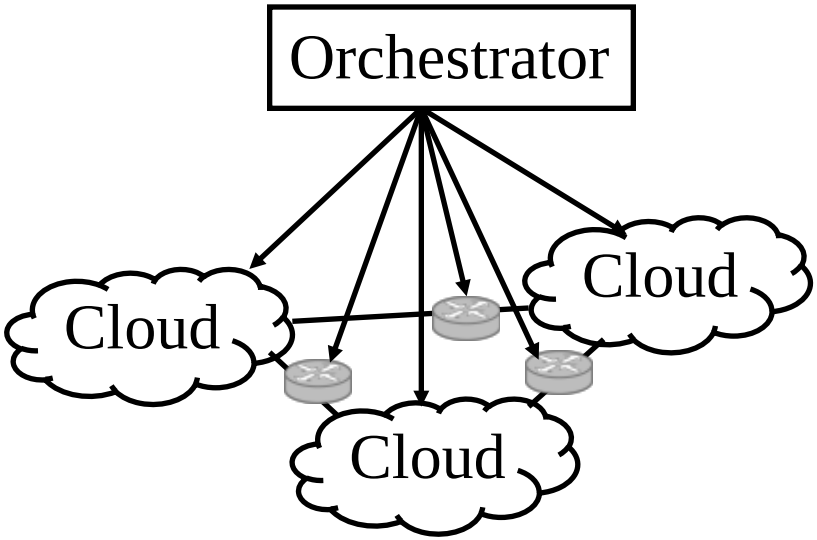
Trend: Software Defined Multi-Cloud

- Orchestrating devices to Orchestrating Clouds

Datacenter Applications

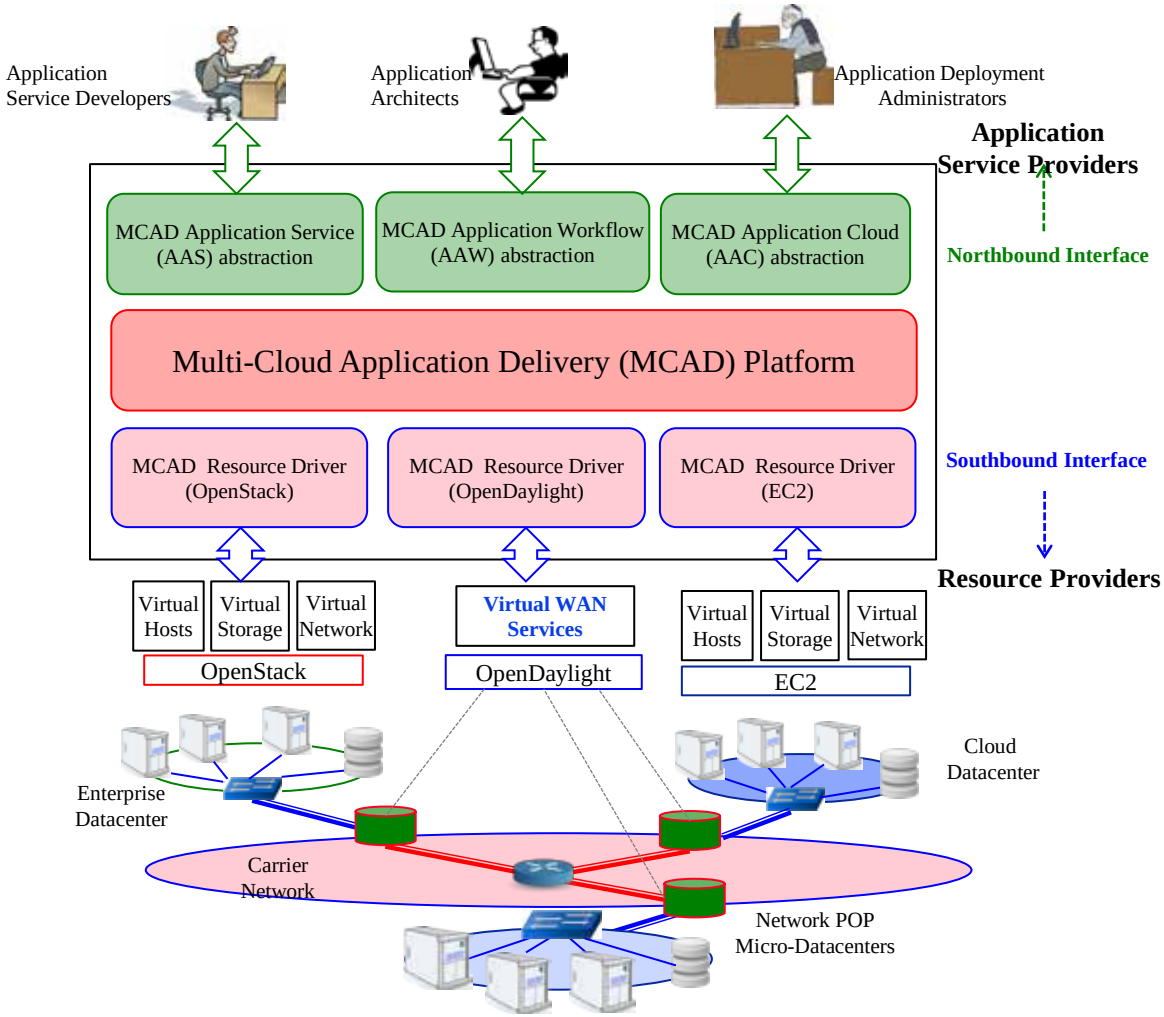


Global Applications



Ref: Subharthi Paul, Raj Jain, Mohammed Samaka, Jianli Pan, "Application Delivery in Multi-Cloud Environments using Software Defined Networking," Computer Networks Special Issue on cloud networking and communications, December 2013, http://www.cse.wustl.edu/~jain/papers/comnet14.htm

OpenADN Multi-Cloud Management



Ref: Lav Gupta, Raj Jain, Mohammed Samaka, "Analysis of Application Delivery Platform for Software Defined Infrastructures," International Journal of Communication Networks and Distributed Systems, 2016, Vol. 5, http://www.cse.wustl.edu/~jain/papers/ijcnds16.htm

Mobile Healthcare Use Case

Home sensors for patient monitoring

Medical Application Service Provider (Insurance Co)

Multi-Cloud Mobile Application Deployment and Optimization Platform

Hospital Cloud

…

SDN Controller

Insurance Co Cloud

Body Area Network for mobile patient

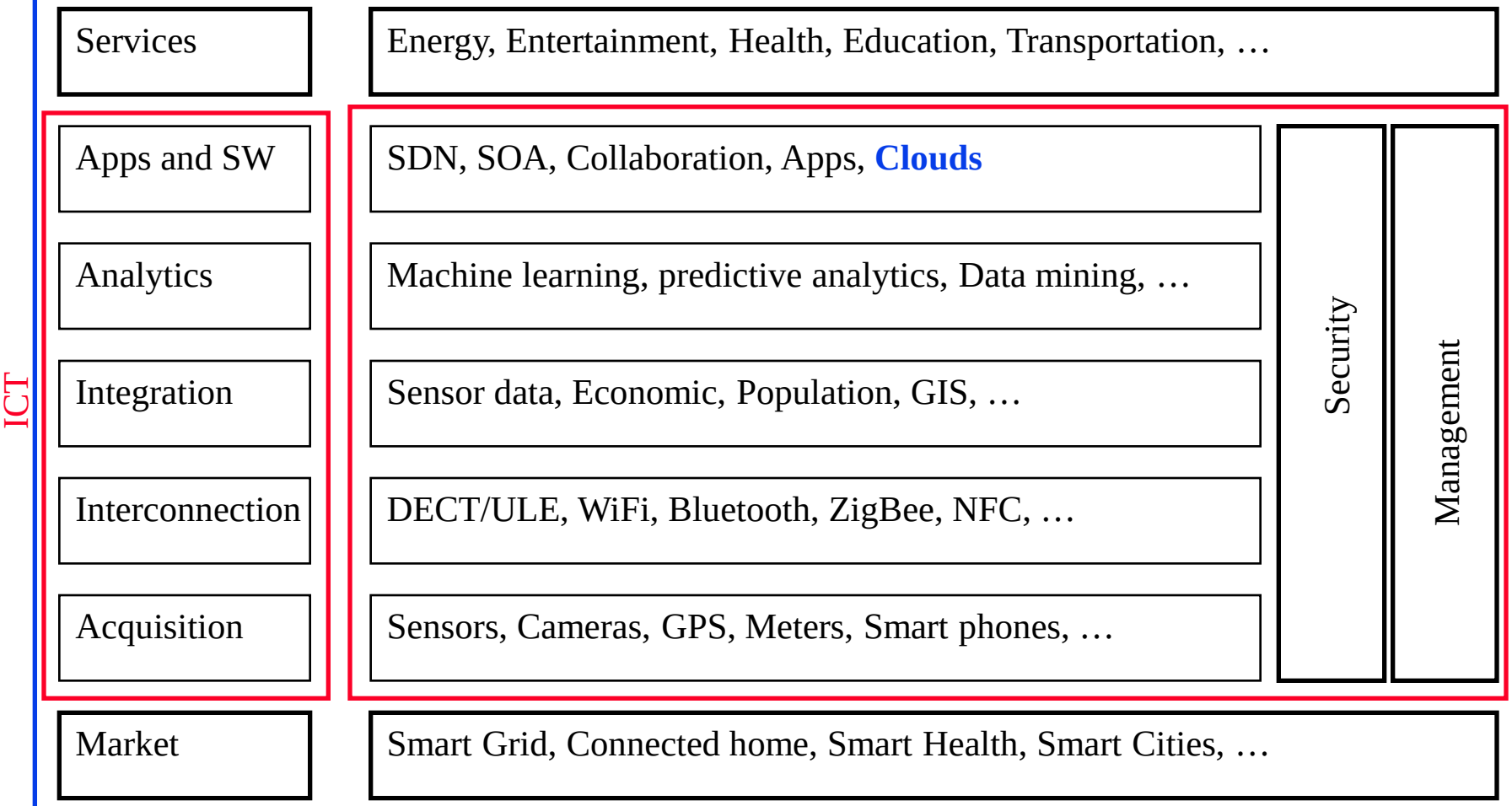
5G Carrier

Mobile Doctor

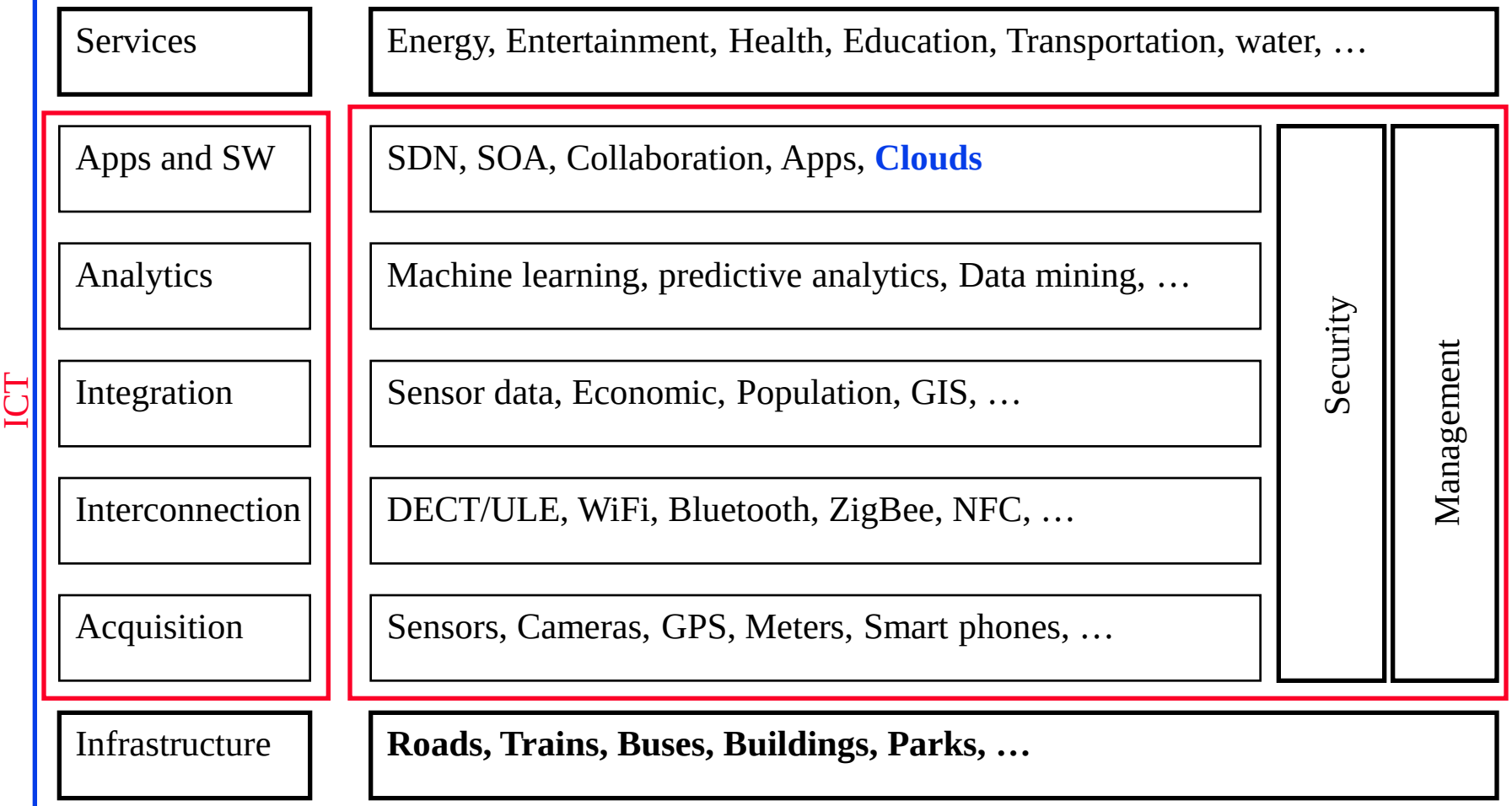
Multi-Cloud Computing

- Most applications are/will be distributed over multiple clouds
- SDN to manage multi-cloud applications
- Healthcare (IoT) use case is an example

A 7-Layer Model of IoT



A 7-Layer Model of Smart Cities



Ref: ISO/IEC JTC 1, "Smart Cities," 2014, http://www.iso.org/iso/smart_cities_report-jtc1.pdf

Areas of Research for IoT/Smart Cities

1. PHY: Smart devices, sensors giving real-time information
2. Datalink: WiFi, Bluetooth, ZigBee, IEEE 802.15.4, …
   Broadband: DSL, FTTH, Wi-Fi, 5G, …
3. Routing: Mesh networking, …
4. Analytics: Big-data, data mining, Machine learning, Predictive analytics, …
5. Apps & SW: SDN, SOA, Cloud computing, Web-based collaboration, Social networking, …
6. Applications: Remote health, On-line education, on-line laboratories, …
7. **Security: Privacy, Trust, Identity, Anonymity, …**

Attack Surface

1. **IoT Devices**
2. **IoT wireless access technology**: DECT, WiFi, Z-wave, …
3. **IoT Gateway**: Smart Phone
4. **Home LAN**: WiFi, Ethernet, Powerline, …
5. **IP Network**: DNS, Routers, …
6. **Higher-layer Protocols**
7. **Cloud**
8. **Management Platform**: Web interface
9. **Life Cycle Management**: Booting, Pairing, Updating, …

Things | Access | Gateway | WAN | Cloud | Users

Internet of Harmful Things

Researchers at DEFCON 3, hacked a smart toilet, making it flush incessantly and closing the lid repeatedly and unexpectedly. Causing a **Denial of Service** Attack.

Ref: http://www.computerworld.com/article/2486502/security0/worm-may-create-an-internet-of-harmful-things--says-symantec--take-note--amazon-.html

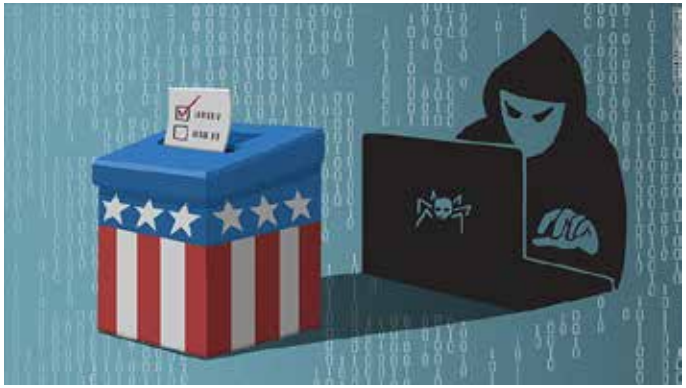
DEFCON

- Hacker's conference
- 20,000+ attendees
- All anonymous

Ref: https://www.ethicalhacker.net/features/opinions/first-timers-experience-black-hat-defcon

DEFCON 2017

- Hacking voting machines
- Hack connected vehicles
- Hacking the cloud
- Hacking travel routers
- Clone RFID in real time
- Breaking the Uber badge ciphers
- Counterfeit hardware security devices, RSA tokens
- Fool antivirus software using AI
- How to track government spy planes
- Break bitcoin hardware wallets
- DARPA Cyber Grand Challenge (2015, 2016)



Confidentiality
Integrity
Authentication

Teaching CIA methods w/o hacking is not sufficient

IoT and Security

- Security is a key issue in the adoption of IoT or Smart Cities
- Hacking is an important part of any security exercise

Blockchains: Centralized to Decentralized

- **Trend**: Make everything decentralized with no central point of control
- Two perfect strangers can exchange money, make a contract without a trusted third party
- Decentralized systems are
  1. More reliable: Fault tolerant
  2. More secure: Attack tolerant
  3. No single bottleneck Þ Fast
  4. No single point of control Þ No monopoly
- Blockchain is one way to do this among **untrusted multi-domain** systems.

Time is a cycle: Distributed vs. Centralized debate

Examples of Centralized Systems

- **Banks**: Allow money transfer between two accounts
- **Currency**: Printed and controlled by the government
- **Stock Exchanges**: Needed to buy and sell stocks
- **Networks:** Certificate Authorities, DNS
- In all cases:
  1. There is a central third party to be trusted
  2. Central party maintains a large database of information Þ Attracts Hackers
  3. Central party may be hacked Þ affects millions
  4. Central party is a single point of failure. Can malfunction or be bribed.

Ref: A. Narayanan, et al, "Bitcoin and Cryptocurrency Technologies," Princeton University Press, 2016, 304 pp.

Networking Applications of Blockchains

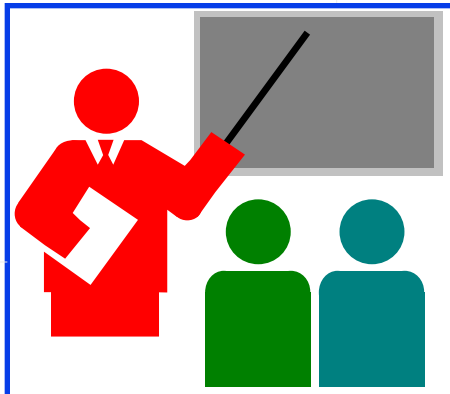
- Multi-Domain Systems:
  - Multiple Cloud Service Providers
  - Multiple cellular providers
  - Multi-Interface devices: WiFi, Cell, Bluetooth, …
  - BGP: BGP Authentication
- Globally Centralized Systems:
  - DNS
  - Certificate Authorities

Explore blockchains for multi-domain/centralized systems

Networking Applications (Cont)

- Public Key Infrastructure
  - Certificate Authorities issue certificates
  - Single Point of Failure
  - Diginotar – Dutch certificate authority was compromised in 2011)
- **NameCoin**: A decentralized key-value registration and transfer platform using blockchains.
  - A decentralized **Domain Names Registry**
  - .bit domain names
- DARPA issued a RFP for Secure Decentralized Messaging using Blockchains

Blockchains for Multi-Domain Large Scale Systems



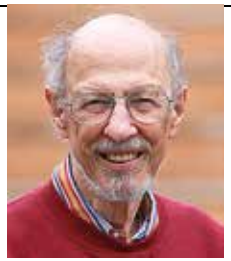
Summary

1. Our goal is to make an impact. Networking was a hot field when we started and still is.
2. The technology that you design should have the right transition strategy, lower cost or killer application
3. Tech Transfer: Make sure your results are based on solid mathematical foundations, validated by simulations and still can be explained simply.
4. You are a company: Select right topics and complete. Complete = Adoption/Implementation

Conclusion

No impact if your research is not adopted

Thanks to Those Who Changed My Life

 Shri Shanti Lal Jain Father	 Smt. Sulochana Devi Jain Mother	 Aunt	 Prof. N. L. Jain GEC, Rewa
 Prof. M. R. Chidambara, I.I.Sc.	 Prof. Raman Mehra, Harvard	 Prof. Ugo Gagliardi, Harvard	 Dr. Terry Potter, DEC
 Prof. Jerome Saltzer M.I.T.	 Prof. Fernando Corbato M.I.T.	 Prof. Jon Turner Wash U	 My Family

Thanks To Colleagues, Mentors, Supporters, Students, …

- Amitabh Mishra
- Anurag Kumar
- Arjan Durresi
- Carey Williamson
- Dah Ming Chiu
- Dan Grossman
- Darlene Fisher
- Dave Oran
- Dave Ward
- David Corman
- David Lucantoni
- Fred Templin
- George Varghese
- H. Anthony Chan
- Imrich Chlamtac
- Jay Iyer
- Jon Crowcroft
- K. K. Ramakrishnan
- Lyman Chapin
- Mahbub Hassan
- Mod Marathe
- Mohammed Samaka
- Mostafa Ammar
- R. Srikant
- Radia Perlman
- Raj Yavatkar
- Rick Bunt
- Sastri Kota
- Shivkumar Kalyanaraman
- Shyam Parekh
- Sonia Fahmi
- Subharthi Paul
- Sudipta Sengupta
- Suman Banerjee
- Victor Bahl
- Vint Cerf
- And many more…

Scan This to Download These Slides

Raj Jain
Jain@wustl.edu
rajjain.com/talks