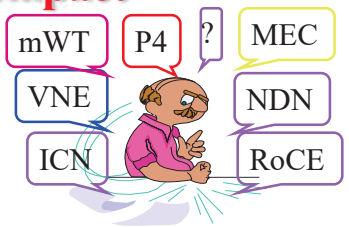
# The Catch-up Game: Quest for the Impact

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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






# 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, …

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

Not-Smart Smart

Networked ⇒ Smart



# Am I in the Right Field to Impact?

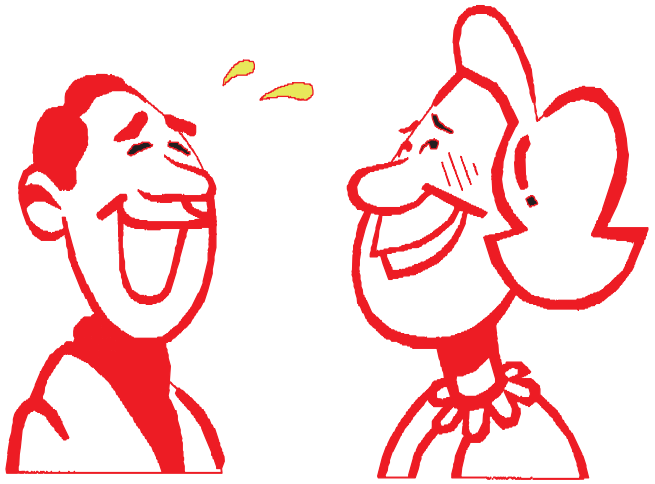
- YES, Networking is hot!

# 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 ⇒ Evolution
   ⇒ Each customer must save.
   2x cost ⇒ 10x performance
2. Killer Application (Video on demand)
3. Coexistence with legacy (Ethernet)
   Existing infrastructure is more important than new technology ⇒ 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

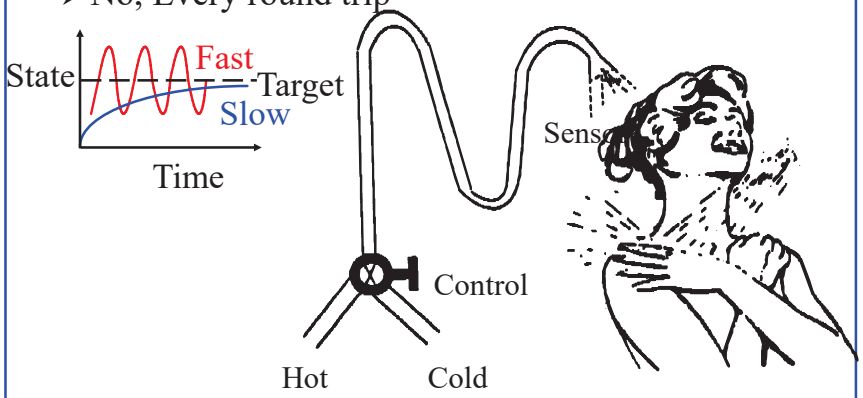
- Collaborators: KK Ramakrishnan, DM Chiu, Bill Hawe
- 1. Implicit Indication: Delay Based – Too noisy
- 2. Explicit Congestion Indication: DECBit
  - Question 1. What to do on a timeout?:
    Conventional Wisdom: Retransmit all packets
    Our Results: No, Drop the congestion window to 1

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.



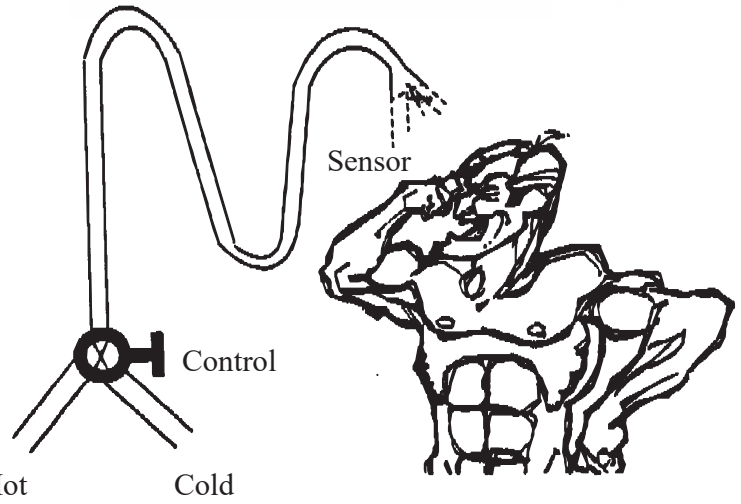
## The Shower Experiment

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






## The Shower Experiment



# Fairness Index

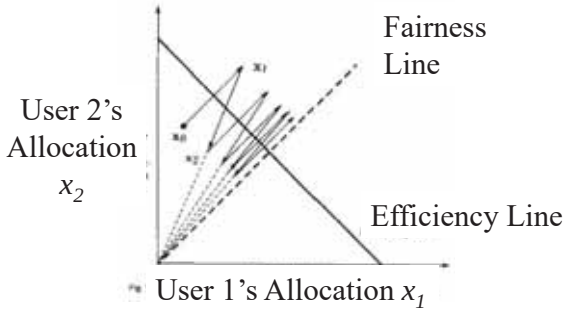
- Question 3: What is a fair/efficient allocation?
- Requirements:
  - Scalable: Apply to n=2 users or n=2 million users
  - Easy to Interpret: Lie between 0 and 1 or 0 and 100%
  - Equal Allocation = 100%
  - If *k* of *n* receive *x* and *n-k* users receive zero throughput: the fairness index is *k*/*n*.

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



# AIMD

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




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
   - 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

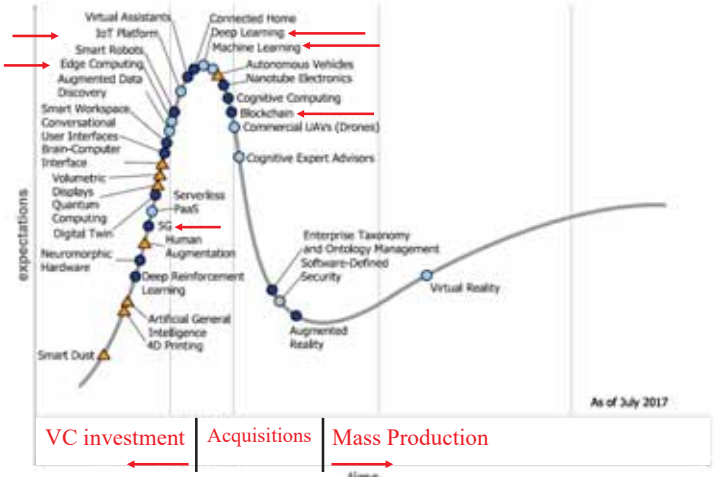


# Adapt to Paradigm Shifts

- 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]



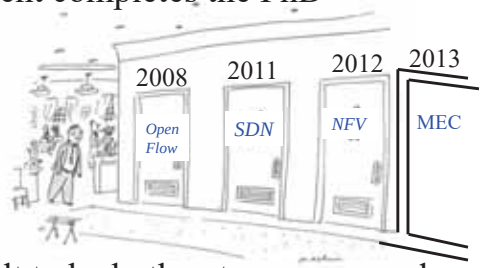
# 4. Don't Be Let Down by a Failure

- 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
  ⇒ Can't move with fast changing world
- Time has shrunk. No topics remains hot for 5 years
  - 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 λ, μ,
- 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.

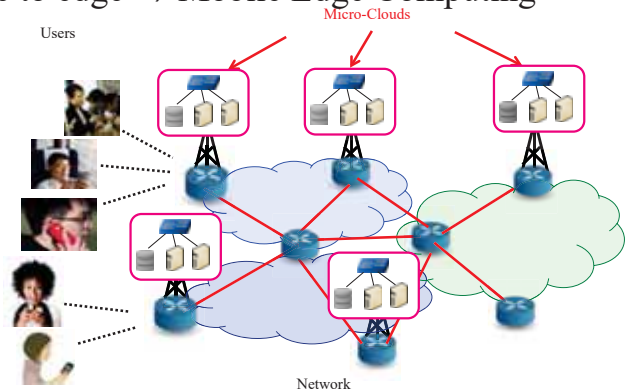


## Trend: Micro-Cloud Computing

- 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
  - μCloud = 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 ⇒ Mobile Edge Computing

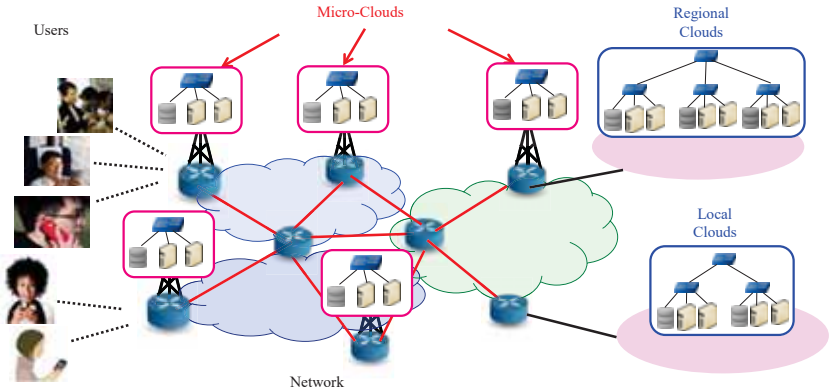



Ref: Lav Gupta, Raj Jain, H. Anthony Chan, "Mobile Edge Computing - an important ingredient of 5G Networks," IEEE Softwarization Newsletter, March 2016, http://www.cse.wustl.edu/~jain/papers/mec16.htm



# Trend: Micro-Services

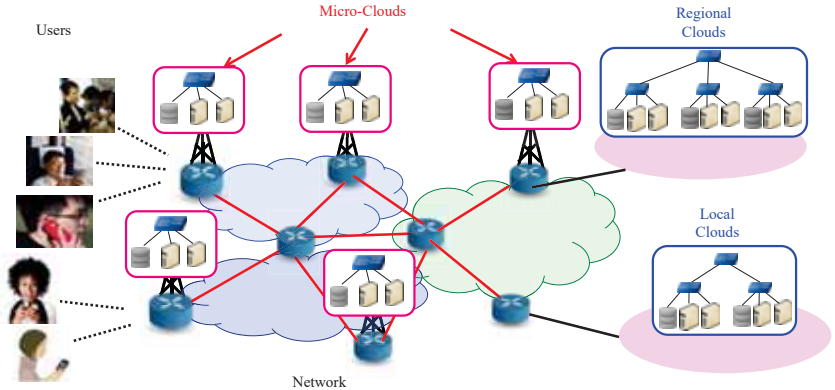
- All major applications, such as, Facebook, Netflix, etc. consist of a number of micro-services instantiated on demand on virtual machines at multiple locations






# Multi-Cloud Hierarchy

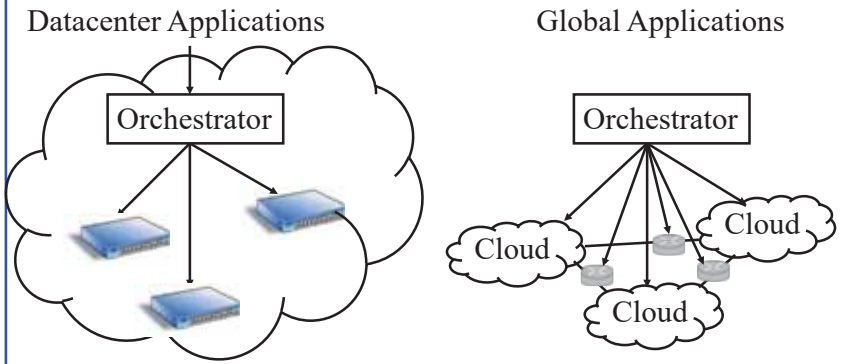
- Wide area clouds, local area clouds (home routers with cloud features), Personal area clouds (cars), body area clouds (smart phone)





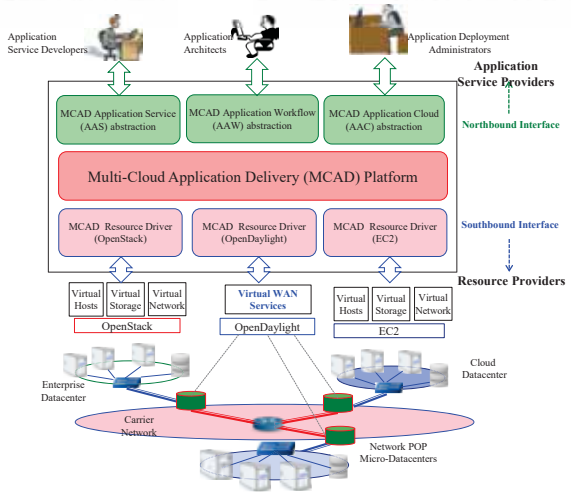

# Trend: Software Defined Multi-Cloud

- Orchestrating devices to Orchestrating Clouds




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

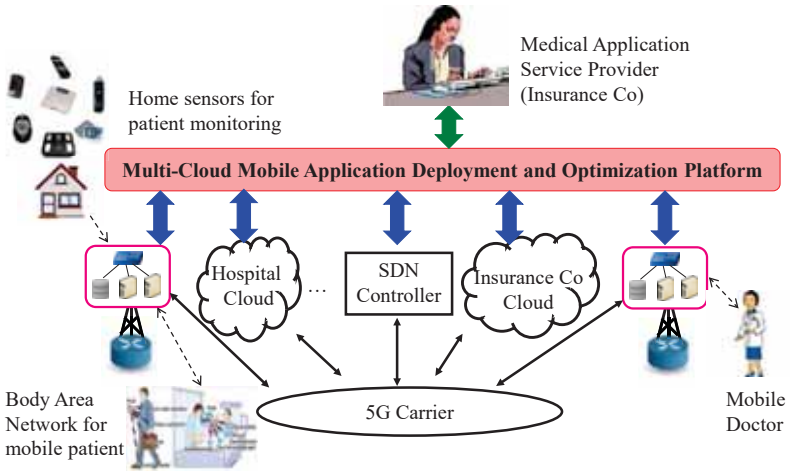
# OpenADN Multi-Cloud Management




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






# 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

| | | |
|---|---|---|
| Services | Energy, Entertainment, Health, Education, Transportation, … | |
| Apps and SW | SDN, SOA, Collaboration, Apps, **Clouds** | Security, Management |
| Analytics | Machine learning, predictive analytics, Data mining, … | |
| Integration | Sensor data, Economic, Population, GIS, … | |
| Interconnection | DECT/ULE, WiFi, Bluetooth, ZigBee, NFC, … | |
| Acquisition | Sensors, Cameras, GPS, Meters, Smart phones, … | |
| Market | Smart Grid, Connected home, Smart Health, Smart Cities, … | |

ICT

# A 7-Layer Model of Smart Cities

| | | | |
|---|---|---|---|
| Services | Energy, Entertainment, Health, Education, Transportation, water, … | | |
| Apps and SW | SDN, SOA, Collaboration, Apps, **Clouds** | Security | Management |
| Analytics | Machine learning, predictive analytics, Data mining, … | | |
| Integration | Sensor data, Economic, Population, GIS, … | | |
| Interconnection | DECT/ULE, WiFi, Bluetooth, ZigBee, NFC, … | | |
| Acquisition | Sensors, Cameras, GPS, Meters, Smart phones, … | | |
| Infrastructure | **Roads, Trains, Buses, Buildings, Parks, …** | | |

ICT

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, …




# 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 ⇒ Fast
  4. No single point of control ⇒ 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 ⇒ Attracts Hackers
  3. Central party may be hacked ⇒ 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

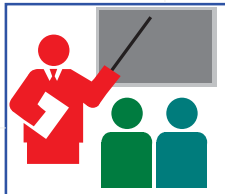


# Networking Applications (Cont)

- 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<br>Father |  Smt. Sulochana Devi Jain<br>Mother |  Aunt |  Prof. N. L. Jain<br>GEC, Rewa |
|  Prof. M. R. Chidambara,<br>I.I.Sc. |  Prof. Raman Mehra,<br>Harvard |  Prof. Ugo Gagliardi,<br>Harvard |  Dr. Terry Potter,<br>DEC |
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# Thanks To Colleagues, Mentors, Supporters, Students, …

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- Dave Ward
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- David Lucantoni
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- Jay Iyer
- Jon Crowcroft
- K. K. Ramakrishnan
- Lyman Chapin
- Mahbub Hassan
- Mod Marathe
- Mohammed Samaka
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- Radia Perlman
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- Shivkumar Kalyanaraman
- Shyam Parekh
- Sonia Fahmi
- Subharthi Paul
- Sudipta Sengupta
- Suman Banerjee
- Victor Bahl
- Vint Cerf
- And many more…



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