The Catch-up Game: Quest for the Impact

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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, …

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

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**

- **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.

**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
  - 19.2 kb/s
  - 1 Mb/s
  - 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


The Shower Experiment

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

State
- Fast
- Target
- Slow

Control
- Hot
- Cold

Sensor
**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 \( k/n \).

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

**AIMD**

- **Question 4:** How to achieve fairness and efficiency?
- **Solution:** Additive Increase, Multiplicative Decrease

**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
  \( \Rightarrow \) 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


2. Bring it to Completion

1. Analyze/develop new algorithm/idea
   - Make most of your time – don’t throw it in dustbin
2. Publish
   - Required for the annual review. But don’t stop here
3. Bring it to IETF/IEEE/ITU
   - ECN by K. K. Ramakrishnan and Sally Floyd
4. Implement and open source
   - Slow start by Van Jacobson
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

- Different Belief Systems
  - Laxmi: Goddess of Wealth
  - Saraswati: Goddess of Knowledge
  - Open Flow
  - SDN
  - NFV
  - MEC
  - 2012 2013
  - 2008 2011 2012 2013
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


**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

**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**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market</td>
<td>Smart Grid, Connected home, Smart Health, Smart Cities, …</td>
</tr>
<tr>
<td>Acquisition</td>
<td>Sensors, Cameras, GPS, Meters, Smart phones, …</td>
</tr>
<tr>
<td>Interconnection</td>
<td>DECT/ULE, WiFi, Bluetooth, ZigBee, NFC, …</td>
</tr>
<tr>
<td>Integration</td>
<td>Sensor data, Economic, Population, GIS, …</td>
</tr>
<tr>
<td>Analytics</td>
<td>Machine learning, predictive analytics, Data mining, …</td>
</tr>
<tr>
<td>Apps and SW</td>
<td>SDN, SOA, Collaboration, Apps, Clouds</td>
</tr>
<tr>
<td>Services</td>
<td>Energy, Entertainment, Health, Education, Transportation, …</td>
</tr>
</tbody>
</table>


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A 7-Layer Model of Smart Cities

**Services**
- Energy, Entertainment, Health, Education, Transportation, water, ...

**Apps and SW**
- SDN, SOA, Collaboration, Apps, **Clouds**

**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, ...

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/security worms may create an internet of harmful things says symantec take note amazon html](http://www.computerworld.com/article/2486502/security worms 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.


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

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

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