

# Next Generation Internet and Wireless and Mobile Networking Research at Washington University



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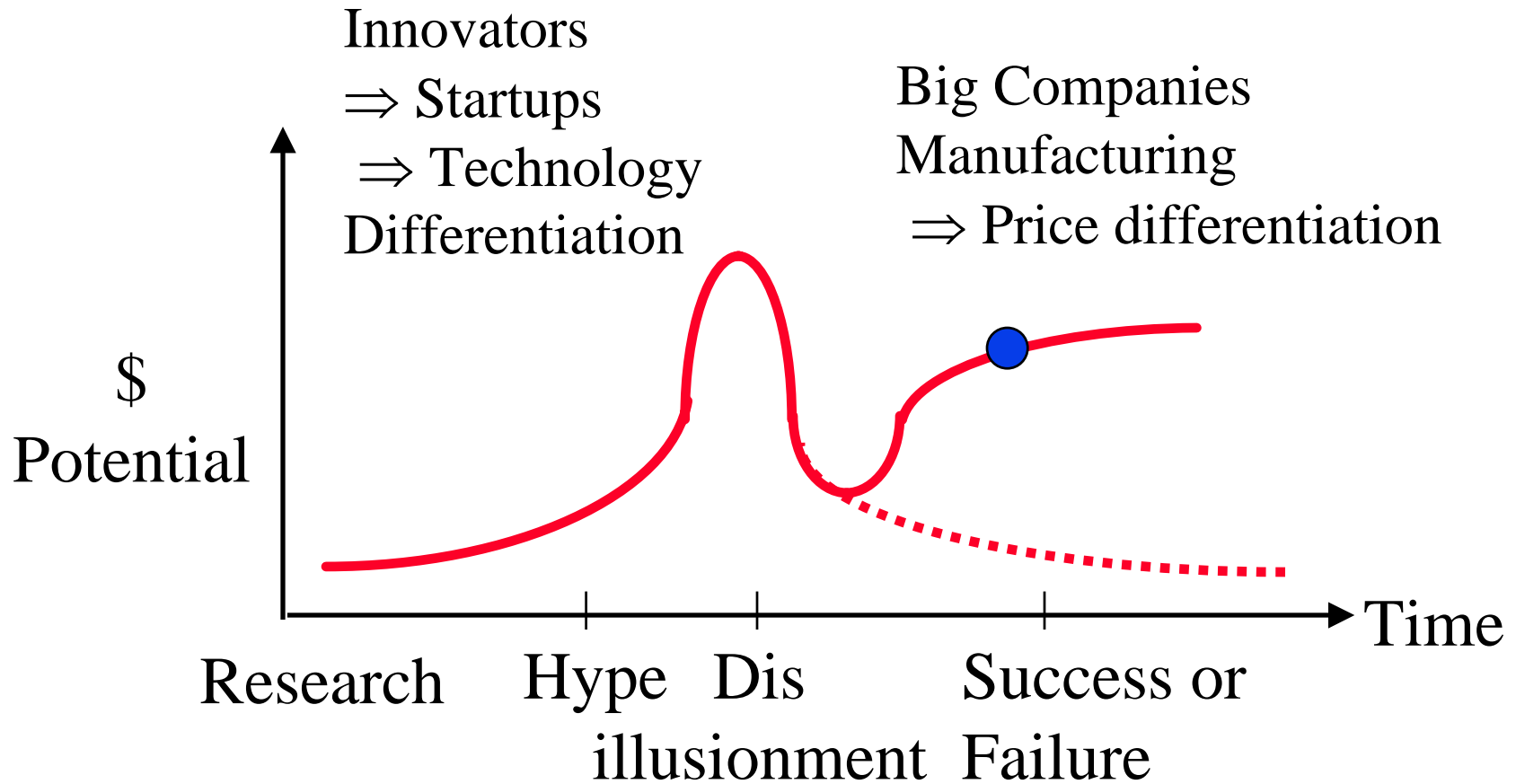
These slides are available on-line at:

<http://www.cse.wustl.edu/~jain/talks/cs59109.htm>



1. Life Cycles of Technologies
2. Problems with Current Internet
3. Our solution for the next generation: Internet 3.0
4. High-Speed Metro-wide wireless networking
5. Related networking research and courses

# Life Cycles of Technologies

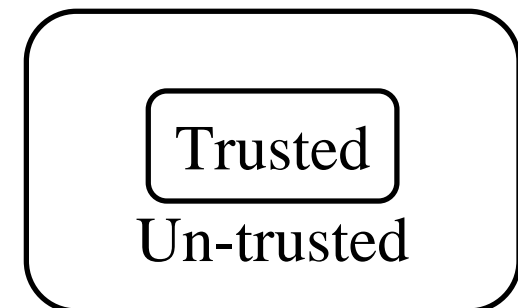


# Internet 3.0

- ❑ National Science Foundation has been working on a large research and infrastructure program on next generation Internet
  - Testbed: “Global Environment for Networking Innovations” (GENI)
  - Architecture: “Future Internet Design” (FIND).
- ❑ Most of the networking researchers will be working on GENI/FIND for the coming years
- ❑ Q: How would you design Internet today? Clean slate design.
- ❑ Ref: <http://www.nsf.gov/cise/cns/geni/>
- ❑ Similar programs by research agencies in Europe, Japan, ...
- ❑ Internet 3.0 is our project on the next generation of Internet
- ❑ Named by me along the lines of “Web 2.0”
- ❑ Internet 3.0 is more intuitive than GENI/FIND

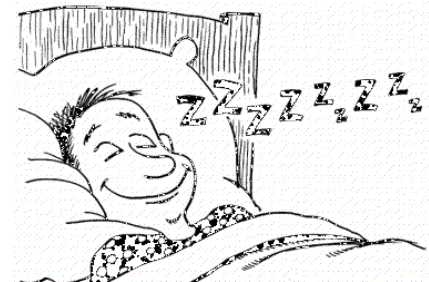
# Problems with Current Internet

1. Security:  
Designed for research  
⇒ Trusted systems  
Used for Commerce  
⇒ Untrusted systems
2. Difficult to represent  
organizational, administrative  
hierarchies and relationships.  
Perimeter based.



## Problems (cont)

4. Identity and location in one (IP Address)  
Makes mobility complex.
5. No representation for real end system: the human.
6. Assumes live and awake end-systems  
Does not allow communication while sleeping.  
Many energy conscious systems today sleep.



Ref: Our Milcom 2006 paper [1]

# Names, IDs, Addresses



**Name:** John Smith

**ID:** 012-34-5678

**Address:**

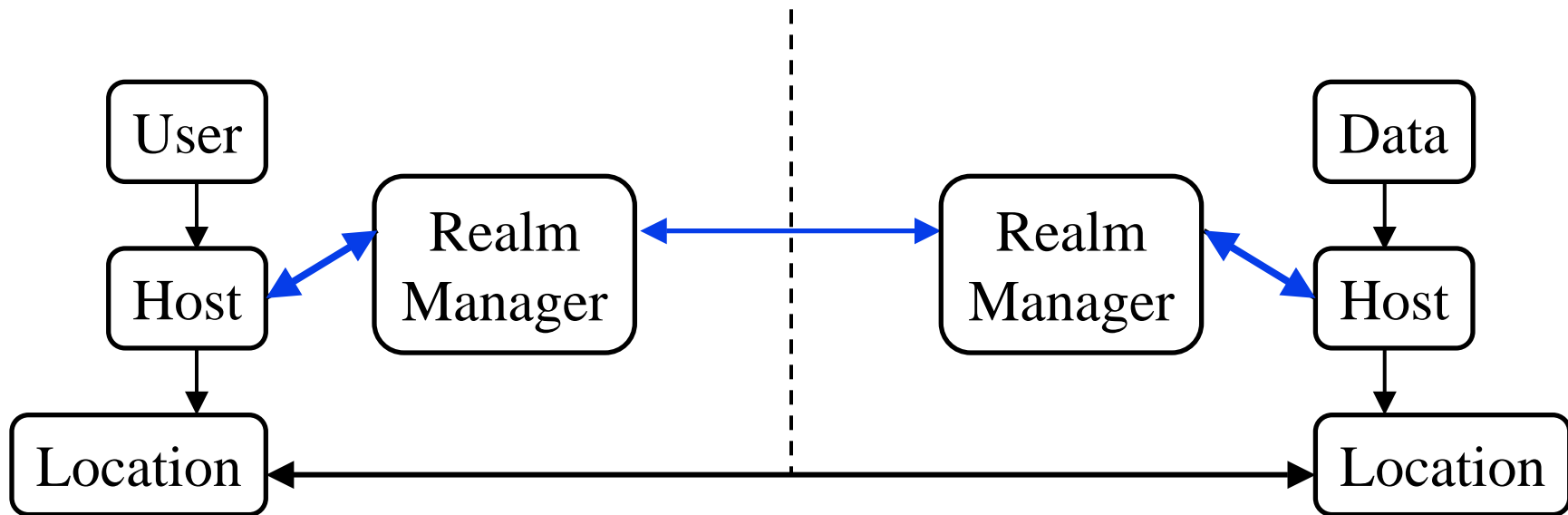
1234 Main Street

Big City, MO 12345

USA

- ❑ Address changes as you move, ID and Names remain the same.
- ❑ **Examples:**
  - Names: Company names, DNS names (microsoft.com)
  - IDs: Cell phone numbers, 800-numbers, Ethernet addresses, Skype ID, VOIP Phone number
  - Addresses: Wired phone numbers, IP addresses

# Id-Locator Split Architecture (MILSA)



- ❑ Realm = An administrative domain
- ❑ Realm managers:
  - Resolve current location for a given host-ID
  - Allow mobility, multi-homing, location privacy
  - Enforce policies: authentication, authorization, privacy

❑ Ref: Our Globecom 2008 paper [2]

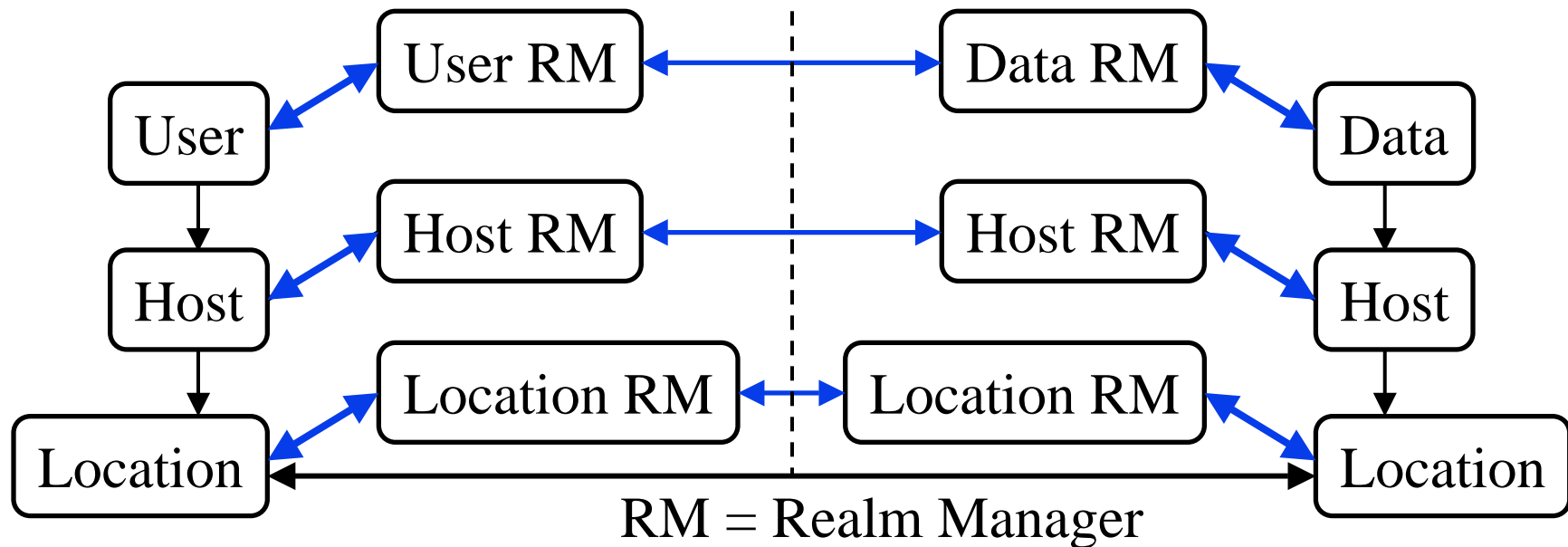


# User- Host- and Data Centric Models

- ❑ All discussion so far assumed host-centric communication
  - Host mobility and multihoming
  - Policies, services, and trust are related to hosts
- ❑ User Centric View:
  - Bob wants to watch a movie
  - Starts it on his media server
  - Continues on his iPod during commute to work
  - Movie exists on many servers
  - Bob may get it from different servers at different times or multiple servers at the same time
- ❑ Can we just give addresses to users and treat them as hosts?  
No! ⇒ Policy Oriented Naming Architecture (PONA)

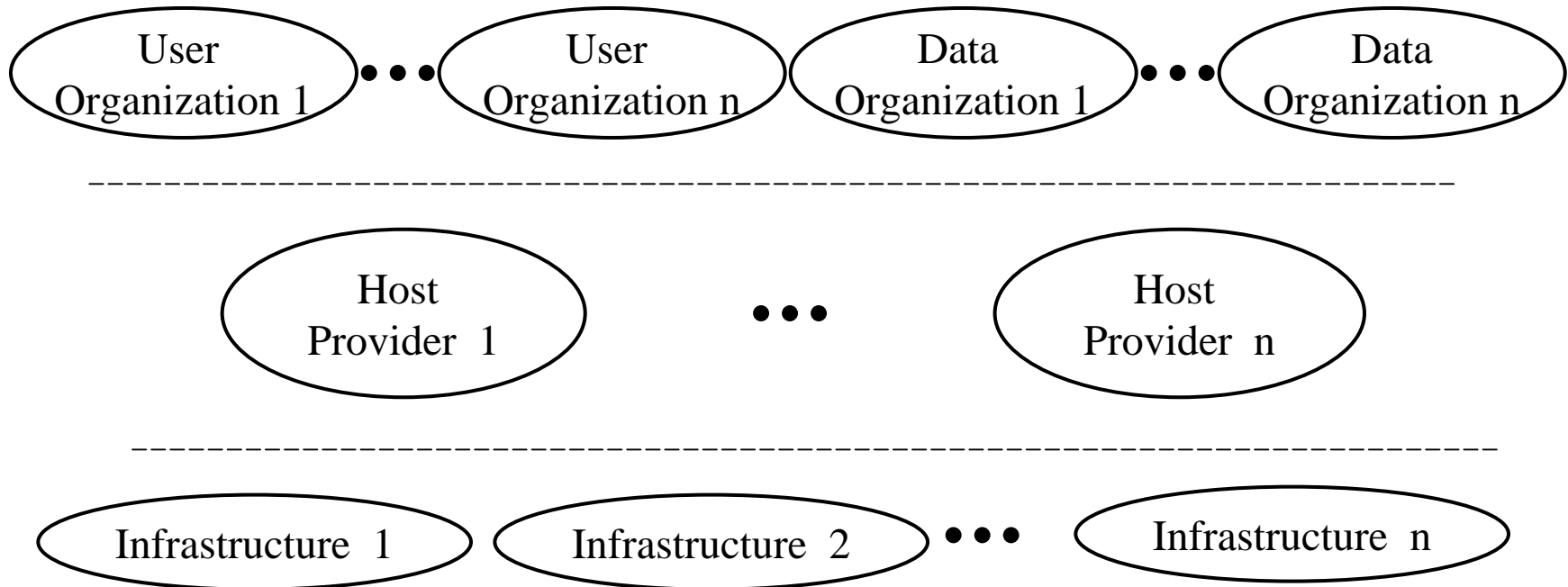


# Policy Oriented Naming Architecture

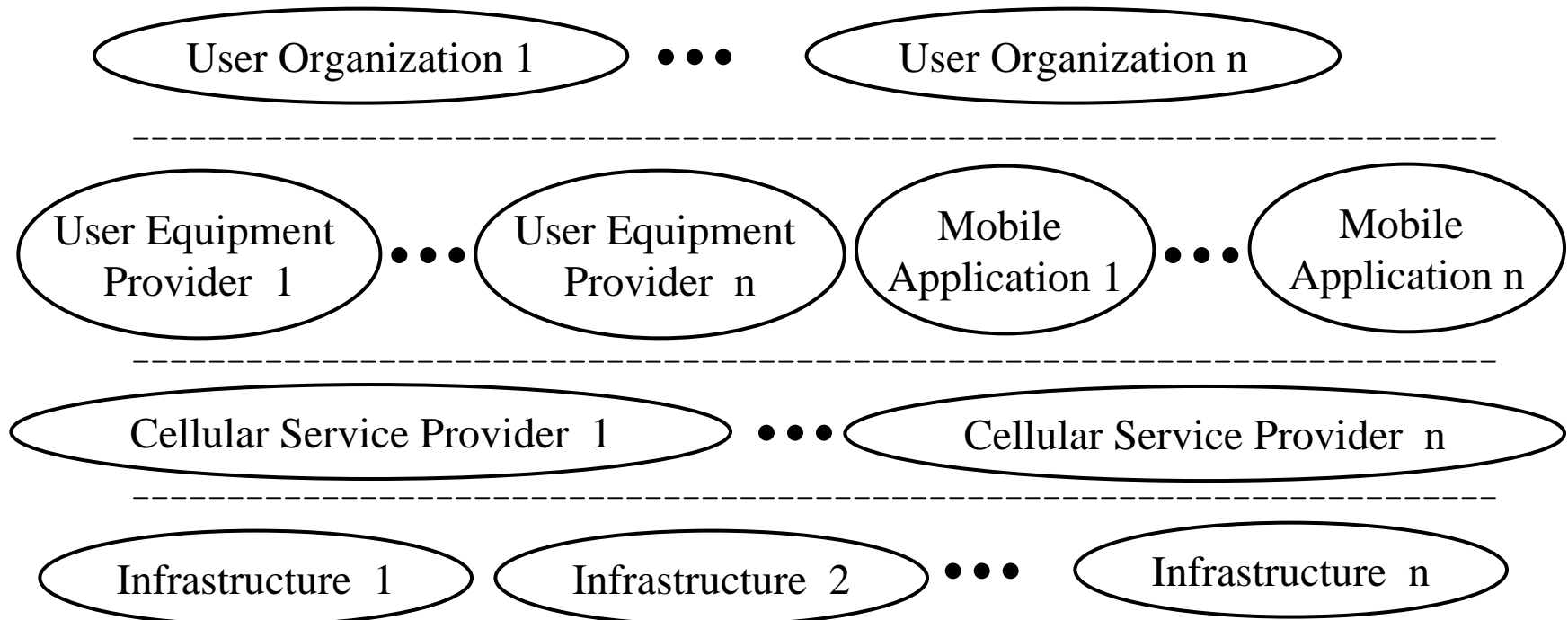


- ❑ Both Users and data need hosts for communication
- ❑ Data is easily replicable. All copies are equally good.
- ❑ Users, Hosts, Infrastructure, Data belong to different realms (organizations)  $\Rightarrow$  3-Tier virtualization
- ❑ Ref: Our PONA paper [3]

# Cloud Computing



# Cellular Networks of the Future



## ❑ Other Examples:

- P2P: File sharing groups over hosts over infrastructure
- Distributed Services: Services and data over hosts over net
- National Security: Infrastructure vs national boundaries

# Key Distinction of Our Research

- ❑ Research topic of current interest to Industry
- ❑ Funded by industry partners
- ❑ Impact real-world by participating in standards organizations and industry forums:  
ATM Forum, IEEE Standards, American National Standards Institute (ANSI), International Telecommunications Union (ITU), Internet Engineering Task Force (IETF), Internet Research Task Force (IRTF), WiMAX Forum
- ❑ Work on long term as well as short term research

# Impact of Our Past Research

- ❑ Reducing load on timeout  $\Rightarrow$  Implemented in slow start in TCP
- ❑ DECbit allows routers to indicate congestion by a bit in the packet header  $\Rightarrow$  Implemented in almost all networking architectures since 1984
  - Forward Explicit Congestion Notification (FECN) bit in frame relay
  - Explicit Forward Congestion Indication (EFCI) bit in ATM cells
  - Explicit congestion notification (ECN) bits in every TCP/IP packet based on our DECbit research
- ❑ Explicit Rate based feedback for Available bit rate (ABR) service in ATM Networks
- ❑ In Citeseer's top 50 "most cited authors in Computer Science"

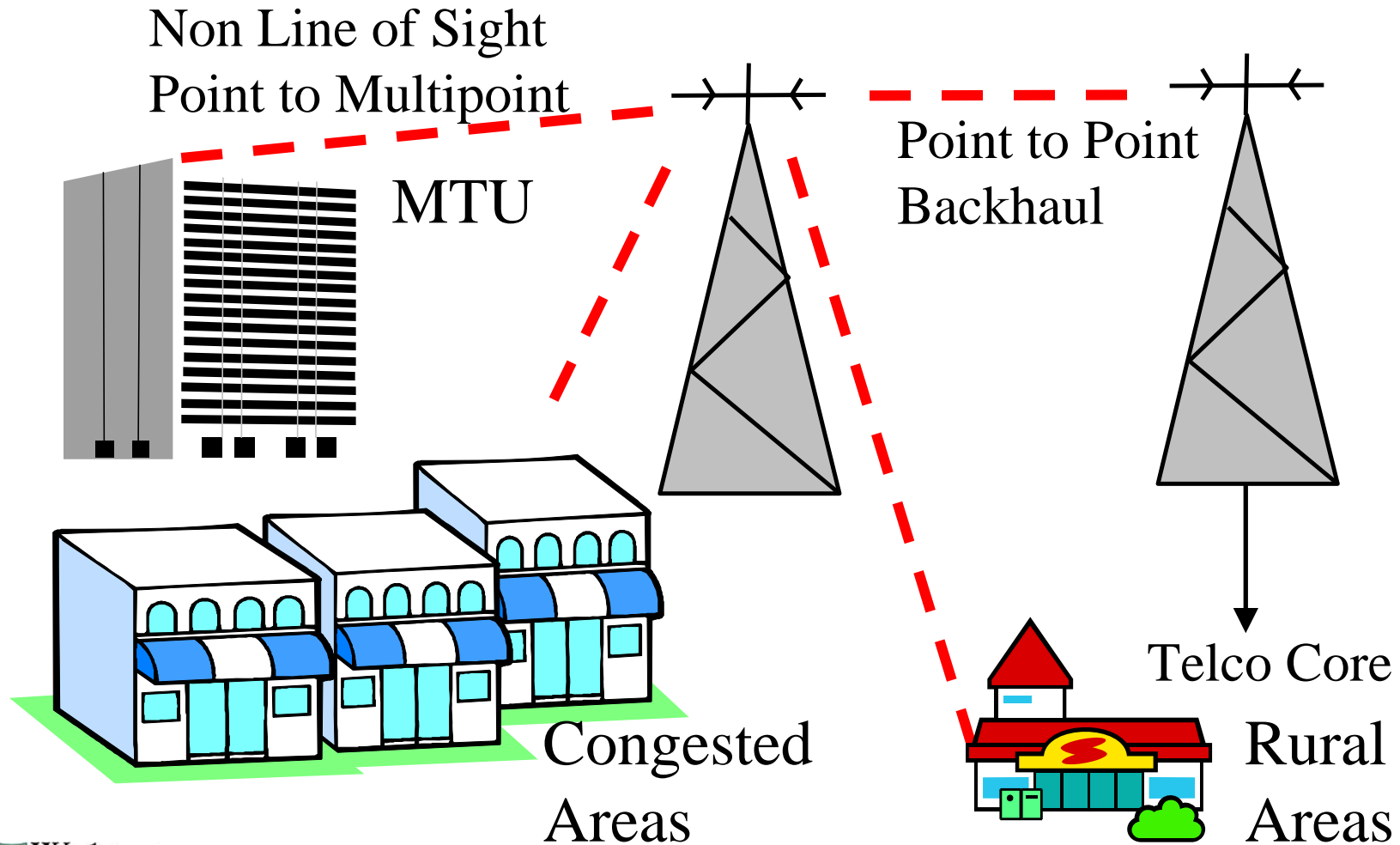
# Telecom Revenues [ITU]

|                          | 1997       | 1998        | 1999        | 2000        | 2001        | 2002        | 2003        | 2004 | 2005 | 2006 | 2007 | 2008<br>Est. |
|--------------------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|------|------|------|------|--------------|
| Telephone (Fixed)        | 437        | 456         | 476         | 477         | 479         | 478         | 475         | 552  | ...  | ...  | ...  | ...          |
| International (Retail)   | 54         | 56          | 58          | 60          | 56          | 52          | 48          | 32   | ...  | ...  | ...  | ...          |
| Mobile                   | 142        | 172         | 223         | 278         | 317         | 364         | 414         | 506  | 579  | 636  | ...  | ...          |
| Other (Leased+Data)      | 133        | 139         | 155         | 165         | 180         | 195         | 210         | 210  | ...  | ...  | ...  | ...          |
| <b>Total Rev (B USD)</b> | <b>946</b> | <b>1015</b> | <b>1123</b> | <b>1210</b> | <b>1232</b> | <b>1314</b> | <b>1426</b> | ...  | ...  | ...  | ...  | ...          |
| Fixed phone lines (M)    | 792        | 838         | 904         | 975         | 1034        | 1083        | 1135        | 1204 | 1262 | 1263 | 1278 | 1267         |
| Mobile subscribers (M)   | 215        | 318         | 490         | 738         | 961         | 1157        | 1417        | 1763 | 2219 | 2757 | 3305 | 4100         |
| Intl phone minutes (B)   | 81         | 91          | 103         | 114         | 120         | 127         | 141         | 166  | 179  | 183  | ...  | ...          |
| Personal computers (M)   | 325        | 375         | 435         | 500         | 555         | 615         | 650         | 775  | 808  | ...  | ...  | ...          |
| Internet users (M)       | 117        | 183         | 275         | 390         | 489         | 616         | 721         | 867  | 989  | 1168 | 1344 | 1542         |

□ More than 30% of revenues from mobile wireless and growing.

□ Ref: [http://www.itu.int/ITU-D/ict/statistics/at\\_glance/KeyTelecom99.html](http://www.itu.int/ITU-D/ict/statistics/at_glance/KeyTelecom99.html)

# Metropolitan High-Speed Wireless: WiMAX





# IEEE 802.16 (WiMAX): Key Features

- ❑ WiMAX = Wireless Interoperability for Microwave Access ⇒ Industry group for interoperability
- ❑ Up to 50 km or Up to 70 Mbps.
- ❑ Data rate vs Distance trade off w adaptive modulation.  
⇒ High rate near the tower.  
Lower as distance increases
- ❑ Offers non-line of site (NLOS) operation
- ❑ Hundreds of simultaneous sessions per channel
- ❑ Allows mobility
- ❑ Robust Security

# WiMAX Deployments 2009



□ Ref: <http://www.wimaxmaps.org/>

# Status of WiMAX

- ❑ WiBro service started in Korea in June 2006.
- ❑ Service available in Bangalore, India since 2007.
- ❑ 470 Deployments worldwide
- ❑ Clearwire offers WiMAX service in 14 markets in USA
- ❑ Deployments expected to double by 2010
- ❑ Intel has developed a multi-band WiMAX/WiFi chipset.  
Available now in new laptops.
- ❑ Competition is LTE (Long-Term Evolution) technology from cellular companies coming in 2 years
- ❑ IEEE is working on the next generation WiMAX (100 Mbps)

# Sample WiMAX Subscriber Stations



Alvarion



Airspan



Axxcelera



Siemens



Aperto  
Washington  
University in St. Louis



Redline



SR Telecom



Telsima

<http://www.cse.wustl.edu/~jain/talks/cs59109.htm>

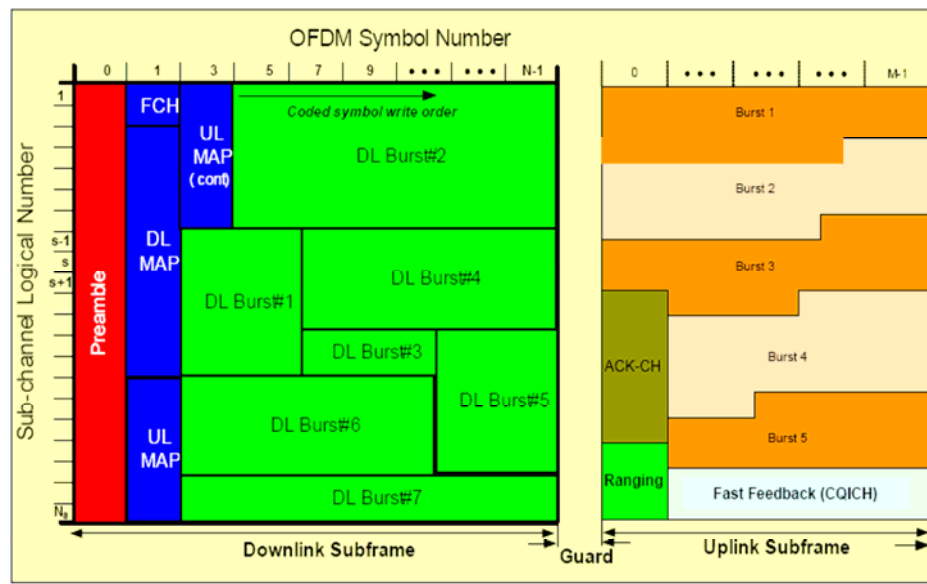
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# WiMAX Simulation Methodology

- ❑ Agreed upon by WiMAX Forum members
- ❑ Can be used by anyone to develop their own simulation
- ❑ Can be used with any modeling platform: NS-2, OPNET, ...
- ❑ Specifies parameter values: ranges and default
- ❑ Specifies features and methods
- ❑ Allows comparison of performance results from different vendors
- ❑ Workloads for key applications: gaming, video streaming, VOIP, FTP, HTTP

Ref: Our paper in IEEE Wireless Magazine, October 2008 issue

# Scheduling in WiMAX



- ❑ Each user is given some frequencies for some time
  - Two dimensional bin packing problem  $\Rightarrow$  NP-Hard
- ❑ Quality of the wireless channel is typically different for different users, and randomly changes with time (on both slow and fast time scales)
- ❑ Ref: Our paper in IEEE J-SAC, Feb 2009

# Mobile Video Modeling

- ❑ MPEG4 compressed video frame sizes can be modeled as a time series
- ❑ Seasonal Auto-Regressive Integrated Moving Average (ARIMA) model for Mobile Video
- ❑ One model that seems to fit many movies
- ❑ Developing a workload generator for use in WiMAX simulation studies
- ❑ Ref: Our SAM paper

## Related Networking Research at Wash U

- ❑ High-Speed Router for GENI: Allows multiple virtual routers with different protocols (Prof. Jon Turner)
- ❑ Embedded Networking: Multi-core communication (Prof. Patrick Crowley )
- ❑ Sensor networking (Prof. Chenyang Lu)

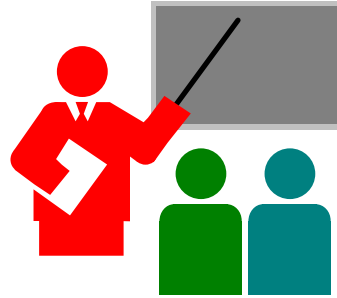
Ref: See respective professor's website for more details



# Networking Courses at WUSTL

1. **CSE 473: Introduction To Computer Networks** (every fall)
2. CSE 471T: Communications Theory And Systems
3. CSE 521S: Wireless Sensor Networks
4. CSE 570A: Reinventing The Internet
5. **CSE 571S: Network Security** (Spring 2011)
6. CSE 572S: Signaling And Control In Communication Networks
7. CSE 573S: Protocols For Computer Networks
8. **CSE 574S: Wireless and Mobile Networking** (Spring 2010)
9. CSE 577M: Design And Analysis Of Switching Systems
10. CSE 578A: Multimedia Computing And Networking
11. CSE 7703: Research Seminar On Networking

# Overall Summary



1. Both short term and long-term research  
Of interest to industry.
2. Active participation industry forums and standards
3. Internet 3.0 architecture, naming, and routing
4. Wireless performance modeling
5. WiMAX scheduling
6. Mobile application characterization

# References

- ❑ Audio/Video recordings and podcasts of several networking classes are available:
  - CSE 473: Introduction to Computer Networks,  
<http://www.cse.wustl.edu/~jain/cse473-09/index.html>
  - CSE 571S: Network Security,  
<http://www.cse.wustl.edu/~jain/cse571-09/index.html>
  - CSE 574S: Wireless Networks,  
<http://www.cse.wustl.edu/~jain/cse574-08/index.html>

## References: Internet 3.0

- Jianli Pan, Subharthi Paul, Raj Jain, Xiaohu Xu, "**Hybrid Transition Mechanism for MILSA Architecture for the Next Generation Internet,**" Proceedings of the Second IEEE Workshop on the Network of the Future (FutureNet II), IEEE Globecom 2009, Honolulu, Hawaii, 30 Nov - 4 Dec 2009, <http://www.cse.wustl.edu/~jain/papers/milsat.htm>
- Jianli Pan, Raj Jain, Subharthi Paul, Mic Bowman, Xiaohu Xu, Shanzhi Chen, "**Enhanced MILSA Architecture for Naming, Addressing, Routing and Security Issues in the Next Generation Internet,**" Proceedings of IEEE International Conference in Communications (ICC) 2009, Dresden, Germany, June 14-18, 2009, <http://www.cse.wustl.edu/~jain/papers/emilsa.htm>
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## References: Internet 3.0 (Cont)

- ❑ Subharthi Paul, Raj Jain, Jianli Pan, Mic Bowman, "**A Vision of the Next Generation Internet: A Policy Oriented Perspective**," Proceedings of British Computer Society (BCS) International Conference on Visions of Computer Science, Imperial College, London, September 22-24, 2008, <http://www.cse.wustl.edu/~jain/papers/pona.htm>
- ❑ Raj Jain, "**Internet 3.0: Ten Problems with Current Internet Architecture and Solutions for the Next Generation**," in Proceedings of Military Communications Conference (MILCOM 2006), Washington, DC, October 23-25, 2006, <http://www.cse.wustl.edu/~jain/papers/gina.htm>

# References: WiMAX Modeling

- Bong-ho Kim, Jungnam Yun, Yerang Hur, Chakchai So-In, Raj Jain, Abdel-Karim Al Tamimi, "**Capacity estimation and TCP performance enhancement over mobile WiMAX networks**," IEEE Communications Magazine, special issue on Mobile WiMAX, Vol. 47, Issue 6, June 2009, pp. 132-141, <http://www.cse.wustl.edu/~jain/papers/capacity.htm>
- Chakchai So-In, Raj Jain, and Abdel-Karim Tamimi, "**Scheduling in IEEE 802.16e Mobile WiMAX Networks: Key Issues and a Survey**," IEEE Journal on Selected Areas in Communications (JSAC), Vol. 27, No. 2, Feb 2009. <http://www.cse.wustl.edu/~jain/papers/sched.htm>
- R. Jain, C. So-in, A. Tamimi, "**System Level Modeling of IEEE 802.16e Mobile WiMAX Networks: Key Issues**," IEEE Wireless Communications, Vol. 15, No. 5, October 2008, <http://www.cse.wustl.edu/~jain/papers/slm.htm> or <http://www.comsoc.org/livepubs/pci/public/2008/oct/index.html>

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- ❑ Chakchai So-In, Raj Jain, and Abdel-Karim Tamimi, "**A Deficit Round Robin with Fragmentation Scheduler for IEEE 802.16e Mobile WiMAX**," Proceedings 2009 IEEE Sarnoff Symposium, Princeton, NJ, Mar 30-Apr 1, 2009, <http://www.cse.wustl.edu/~jain/papers/drrf.htm>

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- A. Tamimi, R. Jain, C. So-in, "**SAM: A Simplified Seasonal ARIMA Model for Mobile Video over Wireless Broadband Networks,**" Proceedings of IEEE International Symposium on Multimedia (ISM2008), December 15-17, 2008, Berkeley, California, USA, <http://www.cse.wustl.edu/~jain/papers/sam.htm>