Control and Management of Future Internet

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THIRTY YEARS OF SYSTEMS RESEARCH EXCELLENCE

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Background and History

Traditional telephone network
- Centralized – intelligence concentrated at a few places
- Expensive and inflexible
- Guaranteed quality-of-service

Traditional Internet
- Limited intelligent – mostly at the edge of the network
- Users/protocols assumed to be cooperative or benign
- Best-effort with no guaranteed quality-of-service
- Focus on tethered networks

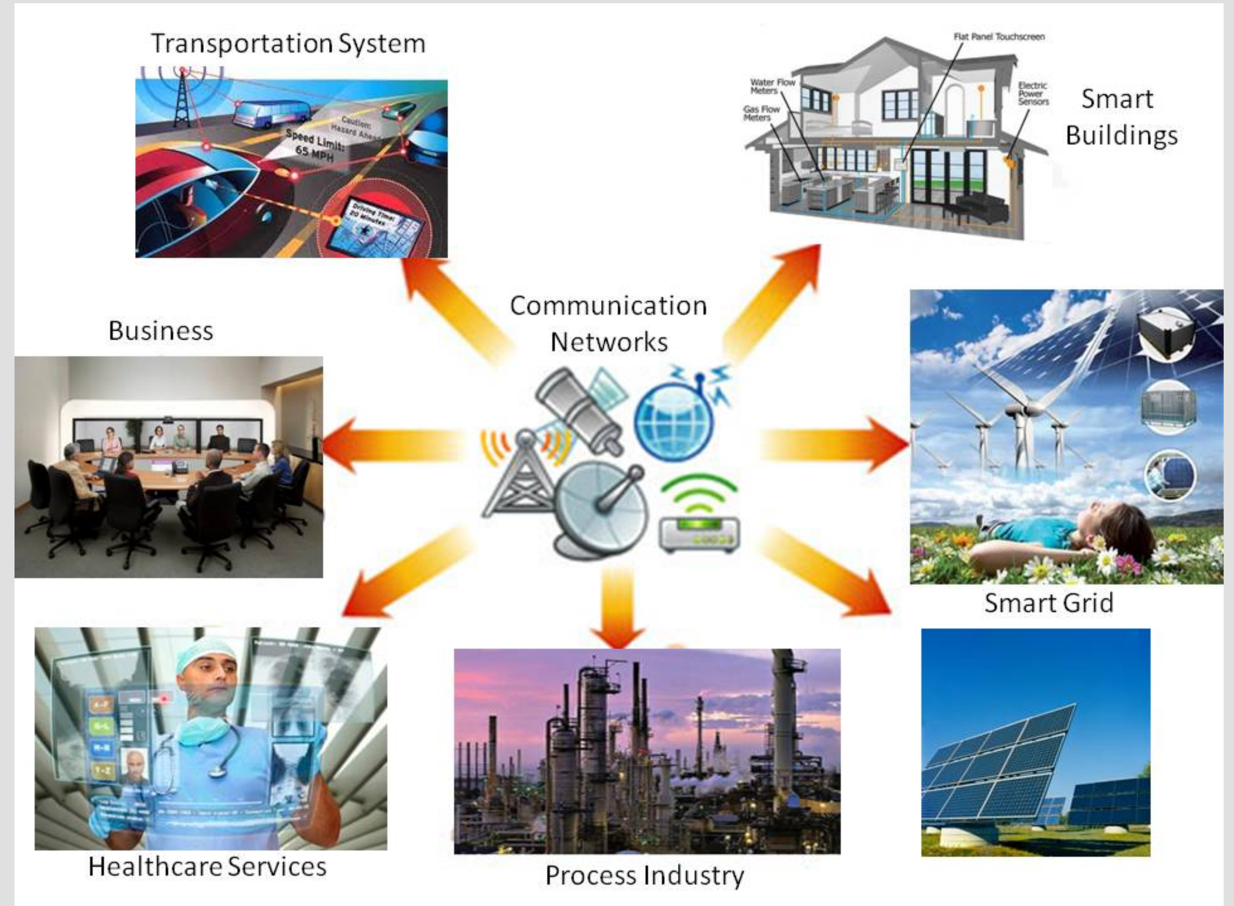
Future Internet
- Demand for ubiquitous information access by mobile users
- Internet of things (IoT) – short, bursty traffic generated by many small devices
- Highly distributed intelligence and management
- Greater security risks

Future Directions

Distributed network management based on game-theoretic framework
- Utility design for efficient network operation
- Learning algorithms with provable convergence to desired operating point

Interdependent security in networks
- Effects of interdependence network properties (e.g., assortativity, clustering) on both local and global network security

Interaction between different types of networks
- Example: Smart grids – power grid vs. communication/control network
- Calls for **more sophisticated network models**



Congestion control
- Increasing demand in the Internet from widely varying applications
- Current congestion control mechanism leads to poor performance over wireless links with large delays
- Showed **parametric sensitivity of network stability** and **propagation of instability** in multi-bottleneck cases
- **Investigated stability of a family of rate control schemes** in the presence of communication delays
  - Proposed rate control schemes with provable stability in the presence of **arbitrary delays**

Traffic engineering
- Existing static routing schemes suffer from inefficient resource utilization and slow adaption to traffic
- Designed an **application-layer overlay network architecture** for traffic engineering
  - Does not require modifications to underlying routing protocols (e.g., OSPF, OLSR)
  - Only makes use of **estimated noisy, real-time measurements** reported by overlay nodes

Cellular network management and resource allocation
- Growing access to information through cellular networks (e.g., smart phones and tablets)
  - Need for higher throughput and spectrum efficiency
- **Spatial diversity** of users via beamforming and MIMO systems
  - **Throughput optimal** MAC scheduling scheme with beamforming
- **Caveat:** Larger and faster fluctuation in inter-cell interference with beamforming/MIMO systems
  - **Inter-cell interference** harder to estimate in advance without coordination of base stations
  - Designed new beamforming algorithms for dealing with **unknown** inter-cell interference at the users

Service level agreement design between service providers
- Previous studies on contract designs assume **risk neutral** players (i.e., content or network service providers)
- Presence of **risk averse players** significantly alters their interaction and resulting equilibria (i.e., feasible operating points)
- Demonstrated in the presence of information asymmetric
  - Some players may always have an **incentive to lie** about their private information
  - Information asymmetry impedes introduction of new network services and applications
  - Other players cannot tell whether some players are lying or not

Multi-hop wireless networks
- Critical communication range for network connectivity with heterogeneous or correlated node mobility
  - Demonstrated **sensitivity of critical communication range to correlation**
- **Topology-based** routing (AODV, DSR, etc.) vs. **position-based** routing in **large** multi-hop wireless networks
  - Overhead for topology maintenance (in topology-based routing) or location service (in position-based routing)
  - Identified **scaling law of overhead** for (i) topology discovery/maintenance under topology-based routing and (ii) location service under proactive and reactive position-based routing
  - Identified an **order-optimal location service scheme** (based on **distributed hash table)**
  - Demonstrated smaller scaling law of overhead under position-based routing than topology-based routing
- **Duration of available on-demand routes** in multi-hop wireless networks
  - Investigated the **distribution of the availability of routes** discovered by on-demand routing schemes
  - Illustrated that their **distribution can be well approximated by an exponential distribution** even with dependence among links along the routes
  - **Expected durations** can be estimated from link parameters

Dynamic spectrum allocation and secondary market for spectrum trading
- Designed an **optimal mechanism** for allocating multiple units of frequency bands
  - **incentive compatible** and **individually rational**
  - Demonstrated the **existence of an incentive for risk neutral sellers to cooperate** in order to increase their expected profit from sales
  - Designed a **revenue sharing scheme** for maintaining cooperation among sellers with individual rationality

Interdependent security
- In many cases, security of an entity or organization dependent on security measures taken by others as well
  - Examples: Cybersecurity, transportation security, epidemics and vaccination
- **Effects of underlying network structure** on security choices/measures of strategic agents largely unknown
- Demonstrated that as the interdependence network becomes more connected (i.e., denser)
  - **Local network risk/security** seen by individual agents **improves**
  - **Global network risk/security** (measured by probability of cascades) **worsens**

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