IoT or CPS
Leveraging Internet for Smarter Grid

Jun Li
Tsinghua University
Current Grid

- Coal
- Nuclear
- Gas

Transmission & Distribution

- Residential
- Industrial
- Commercial
Smart Grid

Transmission & Distribution

Coal

Nuclear

Gas

Solar

Wind

Residential

Industrial

Commercial

Automobile

Trains
(Future) Internet

Datacenters

Transmission & Delivery

Enterprises

MIDs

SOHO
Other Infrastructures

- High speed rail/trains
- Highways
- Airlines
- Petroleum/Gas pipelines
- Water supplies

- Transfer between stations/ports, etc.
- Bandwidth and latency limitations
IoT & CPS

- **Internet of Things**
  - It was mostly computing and communication
  - +Sensors and sensor network
  - +Actuators and control system

- **Cyber Physical System**
  - Tight conjoining of and coordination between computational and physical resources
  - Pervasive/Ubiquitous/Symbiotic Computing
  - $\text{IoT} = \text{CPNet}$: IoT is to implement CPS in a wide-area networking environment
Grid Exists

Conventional Electric Grid

Generation
Transmission
Distribution
Load

Curtsey: A Network Architecture for Localized Electrical Energy Reduction, Generation and Sharing
David Culler
Internet Exists

Conventional Electric Grid

Generation
Transmission
Distribution
Load

Conventional Internet
Intelligent Energy Network as Overlay on Both Conventional Electric Grid and Conventional Internet

IPS: Intelligent Power Switch

Source IPS

Buffer IPS

VPG

energy subnet

Load IPS

Conventional Electric Grid

Conventional Internet

Generation

Transmission

Distribution

Load
Internet of Infrastructure

• Infrastructure needs Internet
  ➢ Best available “nerve” system for infrastructure
  ➢ Data/knowledge and processing power
  ➢ Most advanced human interface

• Internet evolves for infrastructure
  ➢ More (centralized) controllability
  ➢ Better real-time capability
  ➢ Higher reliability
  ➢ Advanced security
OpenFlow Switching

Controller

OpenFlow Switch specification

OpenFlow Switch

Secure Channel

Flow Table

hw

sw

OpenFlow Protocol
SSL

Curtsey: OpenFlow --- Why can’t I innovate in my wiring closet?
Nick McKeown

The Stanford Clean Slate Program
http://cleanslate.stanford.edu
Flow Table Entry
“Type 0” OpenFlow Switch

<table>
<thead>
<tr>
<th>Rule</th>
<th>Action</th>
<th>Stats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Packet + byte counters</td>
</tr>
</tbody>
</table>

1. Forward packet to port(s)
2. Encapsulate and forward to controller
3. Drop packet
4. Send to normal processing pipeline

Switch Port | MAC src | MAC dst | Eth type | VLAN ID | IP Src | IP Dst | IP Prot | TCP sport | TCP dport |
+-------------+---------+---------+----------+---------+--------+--------+---------+-----------+----------+

+ mask

The Stanford Clean Slate Program
http://cleanslate.stanford.edu
OpenFlow Advantage

• Separate intelligence from datapath
  ➢ Centralizes data collection and fusion
  ➢ Allows in depth analysis and granular control

• Flexible flow path control
  ➢ Enables multipath for latency reduction, load balancing, redundancy, and confidentiality
  ➢ Opens up waypoints for middleware, such as access/admission control and intrusion management, as well as middleboxes
  ➢ and a lot more possibilities to be developed
Smart Resource Management

• Global resource optimization
  – Avoid local-optimal solution
  – Centralized management plane

• High-level configuration
  – Avoid on-site configuration effort
  – Automatic low-level control policy deployment

• Possible Approaches
  – Build secure management plane
  – Design reliable discovery mechanism
  – [OpenFlow, CCR’08]
Scalable Computing Capacity

• Computation Architecture
  – Smart decision-making for millions of nodes
  – Scaling up/down and in/out

• Content Organization
  – Massive data generated by nodes
  – Mixed critical and non-critical information

• Possible Approaches
  – Using datacenters for computation [NOX to DC, Hotnet’09]
  – Using hierarchical CACHE and HASH for storage [Onix, OSDI’10]
Fine-grain Control

• Controllability
  – Reliable communication
  – Resource exposure

• Fine-grain
  – Different level of policy enforcing
  – Support extensible protocol processing

• Possible Approaches
  – Support standard management protocol [OpenFlow 2.0]
  – Using both proactive and reactive policy enforcement [DIFANE, Sigcomm’10]
Cost-effective Deployment

• Cost of control elements
  – Millions of nodes
  – Redundant deployment

• Cost of system configuration
  – Expense of field engineering
  – Difficulties in re-deployment

• Possible Approach
  – Using virtualized topology for flexible and extensible deployment [Open vSwitch, HotNet’09]
  – Using network-wide operating system for configuration [Nox, CCR’08]
Security and Reliability

• Secured control plane
  – Sending correct policy
  – Receiving correct message

• Reliable data plane
  – Real-time and critical messages
  – Fault-tolerance

• Possible Approach
  – Out-of-band secure channel with policy check [FlowVisor, OSDI’10]
  – Fine-grain QoS support [OF QoS, WERN’10]
Our Research 1

- Key algorithms for OpenFlow
  - Stateful Inspection
    - for 10~100 Gbps packet classification and session processing
    - on commodity NP and FPGA devices
    - in Infocom'09 and FPT'10
  - Deep inspection
    - for 10 Gbps flow inspection
    - on of-the-shelf FPGA
    - in Globecom'10 and Infocom'11
Our Research II

• OpenFlow-based Service-aware Network
  – Service-aware virtual topology
    • Virtual topology for different service networks
    • Based on switch device virtualization
  – Distributed service-aware processing
    • Offload centralized control to distributed systems
    • Meeting critical performance requirements
    • Saving network bandwidth
Conclusion

• Infrastructure and Internet will evolve into each other and emerge as IoT, CPS, or whatever you call it.
• This requires Internet to gain better controllability, reliability, and security, especially for Smart Grid.
• OpenFlow and its like enable many possible approaches, and brings a lot of challenges and opportunities for networking research.
Many thanks to my colleagues and students, especially Yaxuan Qi

Questions?