An Economy Plane for the Internet

How to charge for innovative network services

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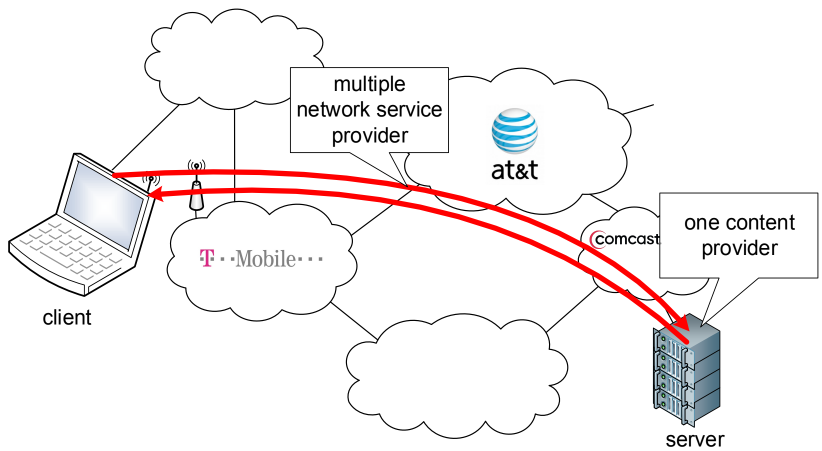
Services in the Internet

- Many important "**services**" that use the Internet:
- "Services" can be distinguished into **two classes**
  - Services on end-systems ("**content**")
    - Distributed applications (e.g., browser accessing data from server)
    - Applications that use the network to communicate
  - Services inside the network ("**network service**")
    - Connectivity between end-systems
    - Caching/buffering of data for faster access

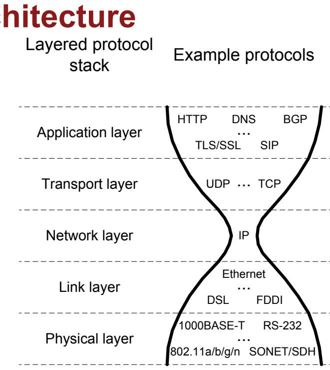
Service in the Internet

- **Example**: access web page
  - One content provider, **multiple network service providers**



The Network Innovation Challenge

- Success of the Internet: **hourglass architecture**
  - Single network layer protocol
  - Diversity at other layers possible
- **Single network layer protocol** makes change difficult
  - Everyone has to agree
  - Single protocol needs to solve all problems
- New architectures are being developed
  - New structures for protocol stack (e.g., virtualization)



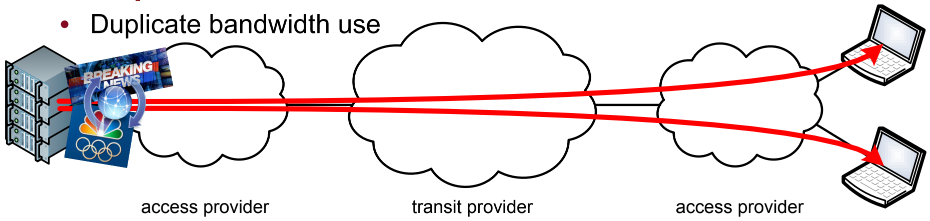
- Thesis of my talk: "**Innovation challenge in Internet is not only technical problem, but also economic problem.**"

Outline

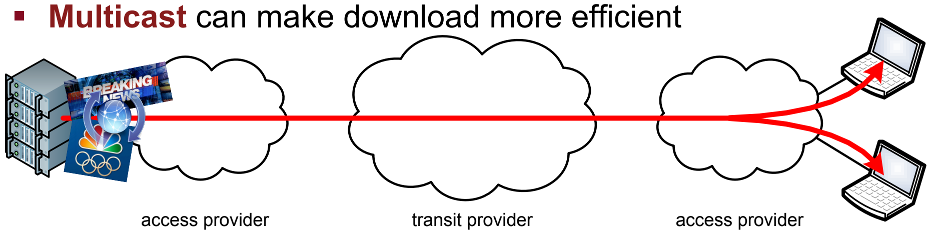
- Introduction
- **Challenges**
  - **Problems with economics in current Internet**
- Economy plane for the Internet
  - ChoiceNet project
  - Competition and Innovation
- Implementation of economy plane
  - Technologies
  - Economics
- Conclusions

Economic Deployment Problem: Multicast

- **Example** scenario: two hosts want to download same content
  - Duplicate bandwidth use



- **Multicast** can make download more efficient



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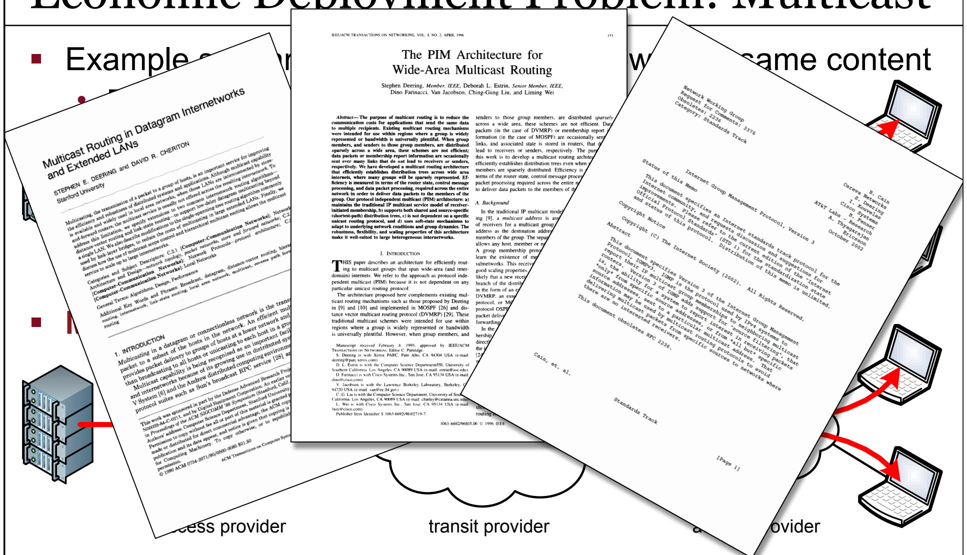
Economic Deployment Problem: Multicast

- Example ... same content



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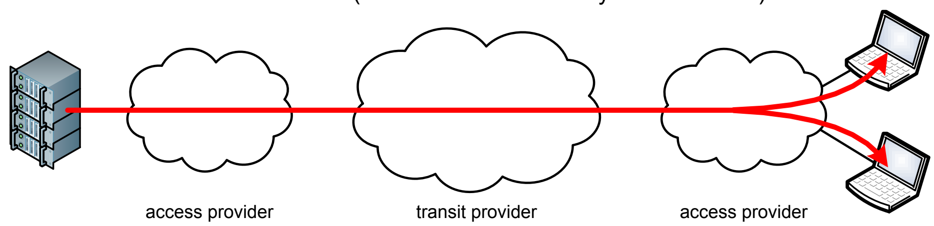
Economic Deployment Problem: Multicast

- Multicast needs **network-wide support**
  - Addressing, routing, etc.
- **Transit provider** is crux of deployment problem
  - Payment from access provider based on bandwidth used
  - Multicast **deployment is highly unattractive**:
    - Increased complexity (need to manage routers with more functionality)
    - Decreased revenue (less bandwidth used by its customers)



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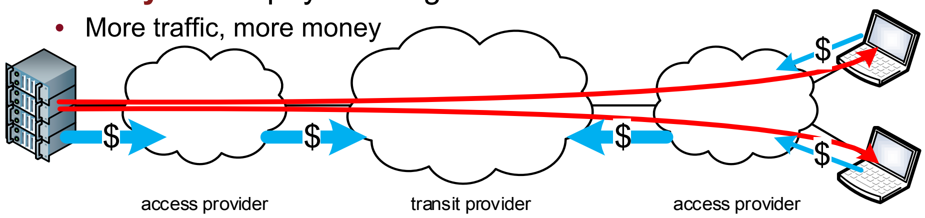
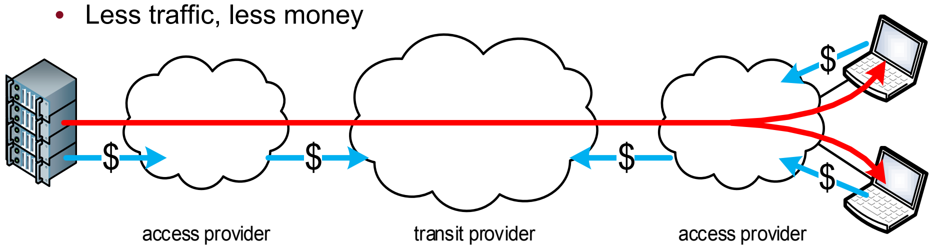
Economic Deployment Problem: Multicast

- **"Money flow"**: payment higher for more bandwidth
  - More traffic, more money



  - Less traffic, less money



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Economic Deployment Problem: Multicast

- N... **...de support**
- T... ...deplo... ...base... **...ly un...** ...man... ...dwid...

Deployment Issues for the IP Multicast Service and Architecture

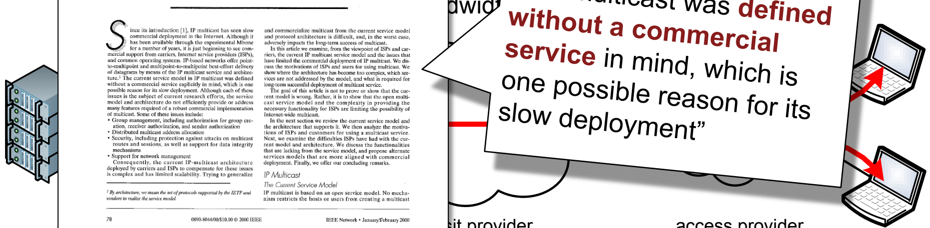
Christophe Diot, Sprint Advanced Technology Labs
Brian Neil Levine, University of Massachusetts
Bryan Lyles, Sprint Advanced Technology Labs
Hassan Kassem, SprintLink
Doug Balensiefen, Sprint

Abstract

IP multicast offers the scalable point-to-multipoint delivery necessary for using group communication applications on the Internet. However, the IP multicast service has seen slow commercial deployment by ISPs and carriers. The original service model was designed without a clear understanding of commercial requirements or a robust implementation strategy. The very limited number of applications and the complexity of the architectural design — which we believe is a consequence of the open service model — have deterred widespread deployment as well. We examine the issues that have limited the commercial deployment of IP multicast from the viewpoint of carriers. We analyze where the model fails and what it does not offer, and we discuss requirements for successful deployment of multicast services.

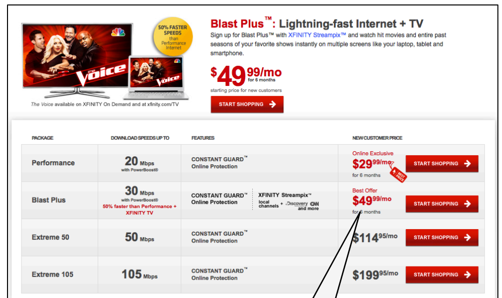
"[…] IP multicast has seen **slow commercial deployment** in the Internet."

"The current service model in IP multicast was **defined without a commercial service** in mind, which is one possible reason for its slow deployment"



Economics in Today's Internet

- Current economic reality for end-users
  - **Long-term contracts** with single provider
  - **No practical choice** for user
    - Cannot easily switch providers
    - Cannot choose services
- How to enable competition?
  - Multiple providers
  - Short-term contracts
- Dynamic **"Economy Plane"**
  - Large choice of offerings
  - Short-term "contracts" with different providers



Outline

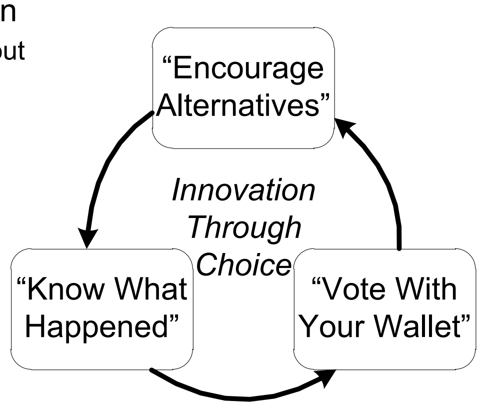
- Introduction
- Challenges
  - Problems with economics in current Internet
- **Economy plane for the Internet**
  - **ChoiceNet project**
  - **Competition and Innovation**
- Implementation of economy plane
  - Technologies
  - Economics
- Conclusions

ChoiceNet Team

- **University of Massachusetts**:
  Tilman Wolf (Principle Investigator)
  Anna Nagurney
- **University of Kentucky**:
  Jim Griffioen
  Ken Calvert
- **North Carolina State University**:
  Rudra Dutta
  George Rouskas
- **RENCI / Univ. of North Carolina**:
  Ilia Baldine
- Many graduate students:
  Sara Saberi, Michelle Li, Xinming Chen, Hao, Cai, Abhishek Dwaraki, Thiago Teixeira, Luis Andres Marentes, …

Principles for ChoiceNet

- Competition drives innovation
  - Choices are exposed throughout protocol stack
  - Users (or their applications) control choices
- "**Encourage alternatives**"
  - Provide services with different functionality, quality, and cost
- "**Know what happened**"
  - Evaluate service experience
- "**Vote with your wallet**"
  - Reward good services through continued use



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Economy Plane

- Main idea: **apply economic principles to network**
  - Network services are offered and sold
  - Contracts are established to buy service
  - Market forces can shape development of network economy
- In our case: create **market-based competition**
  - Forces increase in quality of offerings
  - Forces lower prices for customers
- **Economy plane** implements these principles
  - **Services** are first-class objects in Economy Plane
  - **Contracts** are mechanisms for interaction in Economy Plane
  - **Marketplace** is place where interactions take place

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Concept 1: Services

- **Network services** are “products” in the economy plane
  - **Everything is a service**
  - Example services: bit pipe, payload processing (e.g., VPN termination), storage, caching, processing, content distribution, etc.
  - Service may specify **QoS parameters**
- Description important for interoperability
  - Service offerings specify semantic and performance of service
- Services are offered in the **marketplace**
  - Anyone can offer any service
  - Services can be composed from other services
- Services implement **search** for / **composition** of services
  - E.g., multiple pathlets to create end-to-end path
  - List of choices provided as result

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Concept 2: Contracts

- Contract is established **between customer and provider**
  - Specifies service
  - Specifies payment
- **Payment** can be any form of “**consideration**”
  - Money or money-equivalent
  - Proof of eligibility for service (e.g., company employee)
  - Coupon for free access
- **Enforcement** of contract
  - Access control for service: provider checks customer
  - Verification of service: customer checks provider
- Trusted third party can act as intermediary
  - E.g., marketplace

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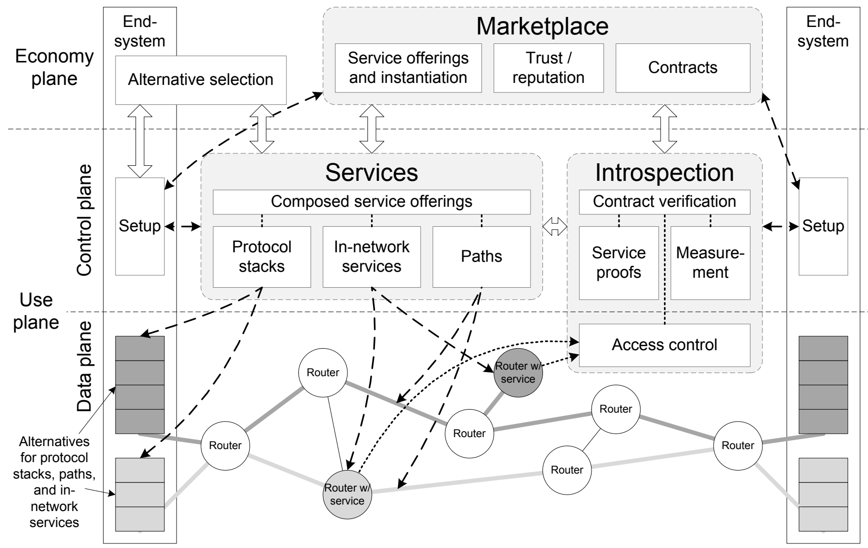
Concept 3: Marketplace

- Place for customers and providers to find each other
  - Set of **well-defined protocols**
    - Advertisement of services
    - Transactions for service use
    - Use of service
  - Foundation for business relationships
- Marketplace provides **trust**
  - Easier to trust one marketplace than many different providers
  - Can act as trusted intermediary for contracts
- **Multiple marketplaces** may coexist (and compete)

ChoiceNet Architecture



Vision: Movie Streaming Example

- Choices for **movie streaming**
  - Technical choices:
    - Different connections, transport, caching, etc.
  - Economic choices:
    - Pay more or less for a particular video experience
    - Technical choices are packaged and sold as **experiences**

- End-user interactions with ChoiceNet
  - **Select, pay for, and expect** a certain experience
- ChoiceNet infrastructure
  - Identify choices, compose suitable offering
  - Distribute money among providers
  - Verify performance

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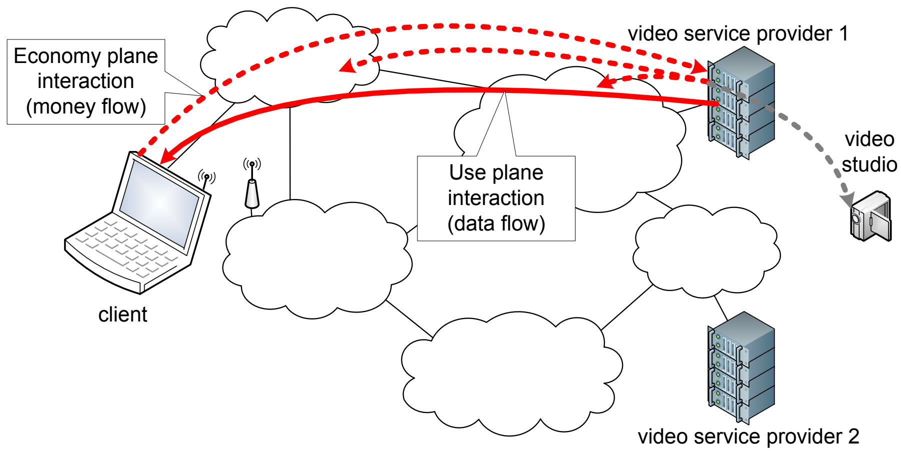
Movie Streaming Example

- User pays video service provider (e.g., Netflix)



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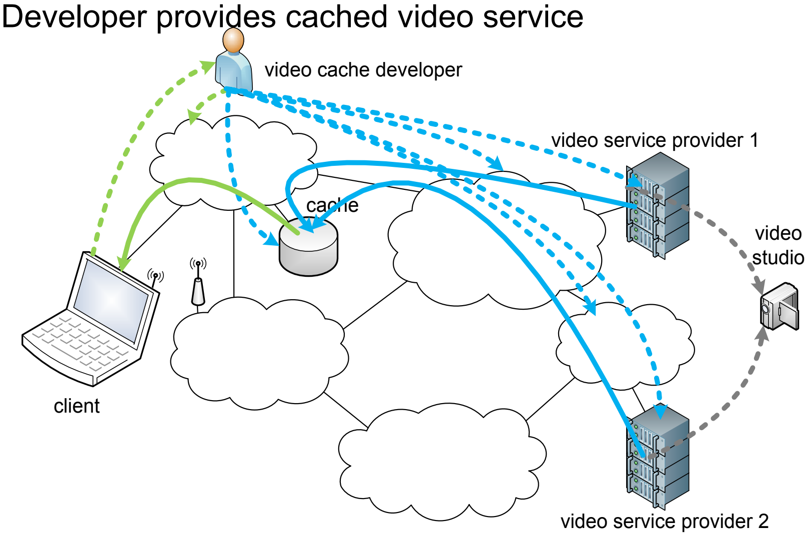
Movie Streaming Example

- Developer provides cached video service



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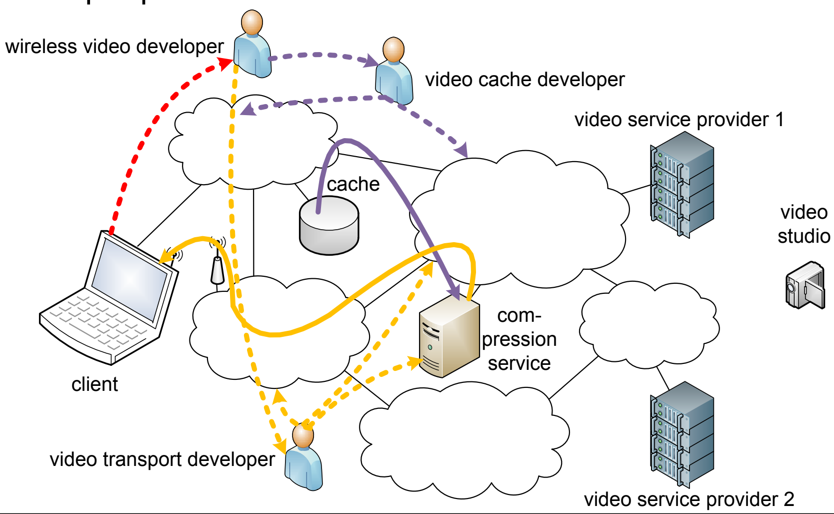
Movie Streaming Example

- Developer provides services without infrastructure



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Summary of ChoiceNet Principles

- **Economic principles** applied to network
- **Economy plane**
  - Services
  - Contracts
  - Marketplaces
- Entities can act as **customer and providers**
  - More complex relationships can be created
- Participation in network economy enables “small” providers to contribute novel ideas
  - Increases competition with established providers
  - Leads to sustainable **innovation**

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- **Implementation of economy plane**
  - **Technologies**
  - **Economics**
- Conclusions

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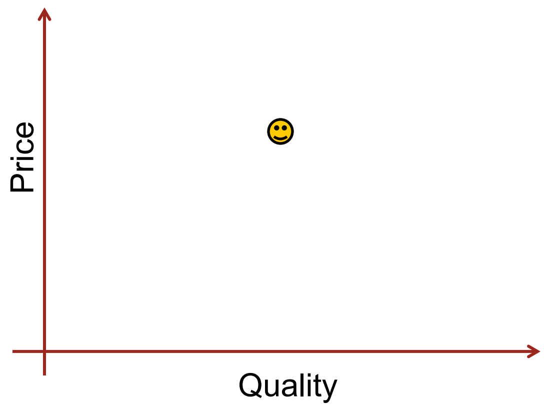
Technical Issues in Economy Plane

- Network services
  - How to define **semantics of service**?
  - How to **find services** that meet application requirements?
- Contracts
  - How to do monetary transaction?
  - How to **enforce contracts**?
    - Provider enforcing access control
    - Customer enforcing service quality
- What happens to providers?
  - Can providers still **make profits**?
- Does competition really lead to **innovation**?
  - Are providers incentivized to innovate?

Market Interactions

- Customer has a **preference** for price and quality



Market Interactions

- Market consists of **many customers**

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Market Interactions

- Providers do **not** know preferences a priori

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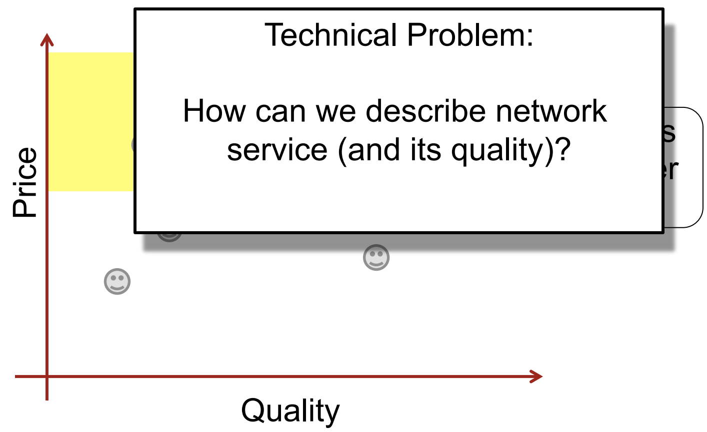
Market Interactions

- Providers **offers service** in marketplace

Market Interactions

- Offer meets preference of **some customers**

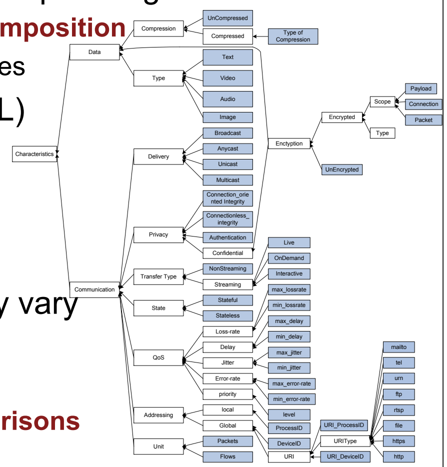


ChoiceNet Service Description

- Service specification based on two aspects:
  - **Requirements** on input for correct operation
    - Semantics of data going in
  - **Transformations** performed by service
    - Semantic changes
- Service "**end-points**" are special cases
  - "Location(s)" where data go in is requirement
  - "Location(s)" where data come out is transformation
- **Composition** by "connecting end-points"
  - Outputs of previous service need to match inputs of next service
  - Using heuristics, inference, linear logic approaches, etc.
  - Only works if semantics of data and transformation are understood

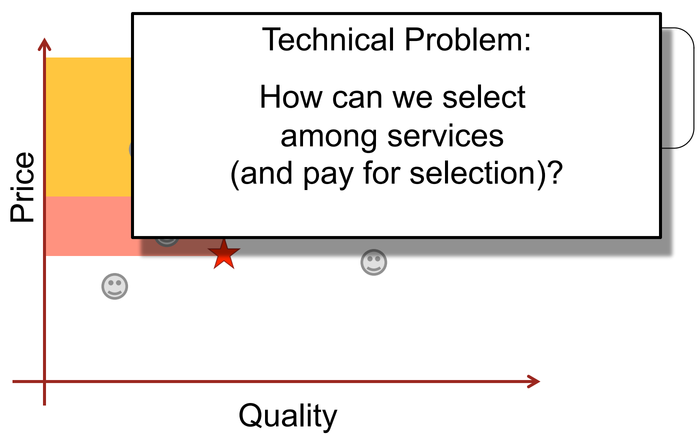
ChoiceNet Service Description

- Necessary for advertisements and planning
  - Need **abstraction for dynamic composition**
  - Need a **common format** for services
- **Web Ontology Language** (OWL) as basis for services
  - Classes of **service attributes** and **relationships** between them
  - Simple **inference rules**
- **Scope** of service semantics may vary
  - Global ontology difficult to maintain
  - Provider may choose any ontology
  - Key requirement is to allow **comparisons**



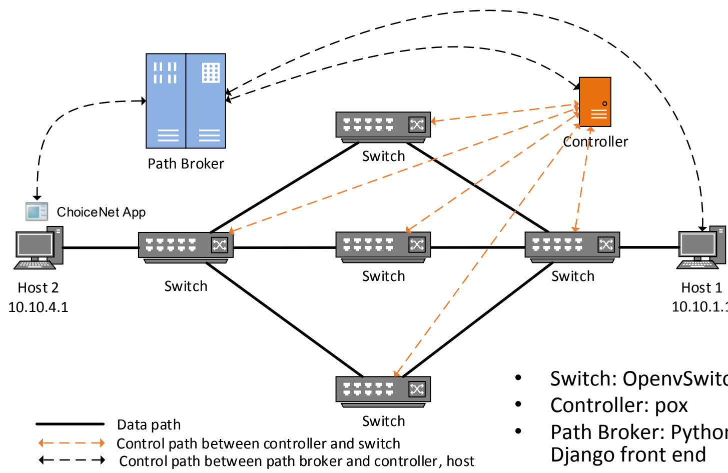
Market Interactions

- **Competing offer** (same or different provider)



SDN-Based ChoiceNet Operation

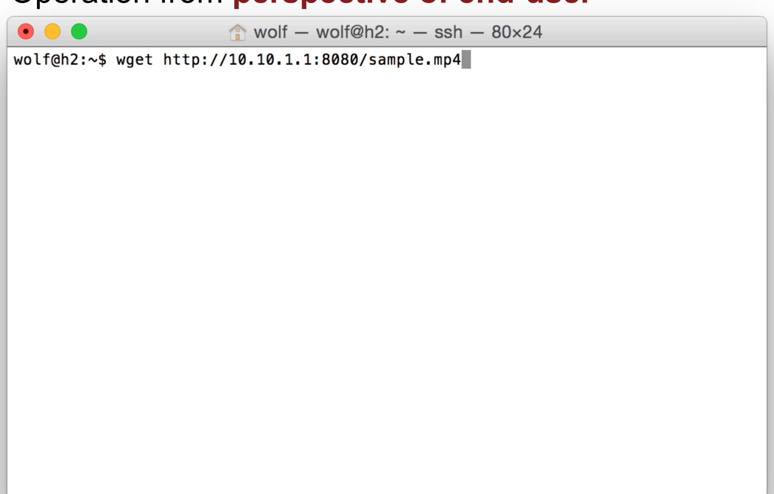
- Multiple end-to-end paths with different price and quality



- Switch: OpenvSwitch
- Controller: pox
- Path Broker: Python server, Django front end

GENI Prototype

- Operation from **perspective of end-user**



GENI Prototype

- ChoiceNet interface on end-system offers **choices**

```
wolf@h2:
--2014-1
Connecti
```

```
wolf — wolf@h2: ~ — ssh — 80×24
wolf@h2:~$ sudo /root/choicenet/geni/start_app.sh
Trying to kill running ChoiceNet App...
kill: usage: kill [-s sigspec | -n signum | -sigspec] pid | jobspec ... or kill
-l [sigspec]
kill: usage: kill [-s sigspec | -n signum | -sigspec] pid | jobspec ... or kill
-l [sigspec]
Starting ChoiceNet App...
User login
Please enter username: customer@choicenet.info
Please enter password:
Connected to marketplace 192.122.236.101

Installing iptable rule for 10.0.0.0/8 port 8080,443...
Installed

Please switch to another terminal and send traffic.
Path choices will be shown here.
SYN Packet intercepted!
Forward recipe:
0. Bandwidth: 10.00 Mbps, Latency: 0.40 ms, Price: 0.18 dollars
1. Bandwidth: 1.00 Mbps, Latency: 0.40 ms, Price: 0.16 dollars
Enter selection:
```


GENI Prototype

- User **chooses 1 Mbps** paths, receives **URL** for payment

```
wolf@h2:
--2014-1
Connecti
```

```
wolf — wolf@h2: ~ — ssh — 80×24
-l [sigspec]
Starting ChoiceNet App...
User login
Please enter username: customer@choicenet.info
Please enter password:
Connected to marketplace 192.122.236.101

Installing iptable rule for 10.0.0.0/8 port 8080,443...
Installed

Please switch to another terminal and send traffic.
Path choices will be shown here.
SYN Packet intercepted!
Forward recipe:
0. Bandwidth: 10.00 Mbps, Latency: 0.40 ms, Price: 0.18 dollars
1. Bandwidth: 1.00 Mbps, Latency: 0.40 ms, Price: 0.16 dollars
Enter selection: 1
Return recipe:
0. Bandwidth: 10.00 Mbps, Latency: 0.40 ms, Price: 0.18 dollars
1. Bandwidth: 1.00 Mbps, Latency: 0.40 ms, Price: 0.16 dollars
Enter selection: 1
Please pay for the services in the following webpage before you use them:
http://192.122.236.101/new/client/paypal/payment/service/69/2/1414112420663/40/
```

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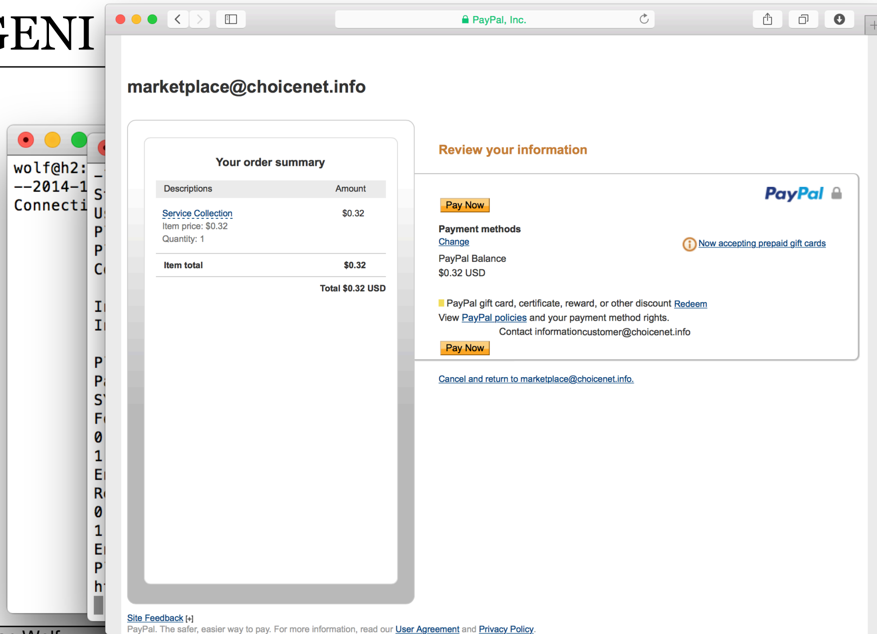
GENI



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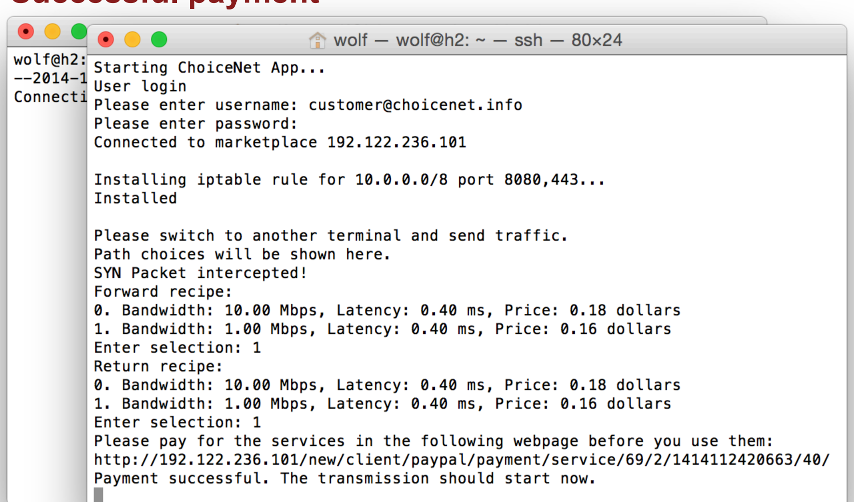
GENI Prototype

- **Successful payment**



GENI Prototype

- Throughput is roughly **1 Mbps**

wolf — wolf@h2: ~ — ssh — 80×24

```
--2014-10-23 21:15:00--  (try:14)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:16:13--  (try:15)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:17:26--  (try:16)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:18:39--  (try:17)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:19:52--  (try:18)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... connected.
HTTP request sent, awaiting response... 200 OK
Length: 73516259 (70M) [video/mp4]
Saving to: `sample.mp4'

 4% [>                                      ] 3,642,672    116K/s  eta 9m 47s
```


GENI Prototype

- User repeats exactly same, but **chooses 10 Mbps** path

```
wolf@h2:
--2014-1
Connecti
```

wolf — wolf@h2: ~ — ssh — 80×24

```
SYN Packet intercepted!
Forward recipe:
0. Bandwidth: 10.00 Mbps, Latency: 0.40 ms, Price: 0.18 dollars
1. Bandwidth: 1.00 Mbps, Latency: 0.40 ms, Price: 0.16 dollars
Enter selection: 1
Return recipe:
0. Bandwidth: 10.00 Mbps, Latency: 0.40 ms, Price: 0.18 dollars
1. Bandwidth: 1.00 Mbps, Latency: 0.40 ms, Price: 0.16 dollars
Enter selection: 1
Please pay for the services in the following webpage before you use them:
http://192.122.236.101/new/client/paypal/payment/service/69/2/1414112420663/40/
Payment successful. The transmission should start now.
SYN Packet intercepted!
Forward recipe:
0. Bandwidth: 10.00 Mbps, Latency: 0.40 ms, Price: 0.18 dollars
1. Bandwidth: 1.00 Mbps, Latency: 0.40 ms, Price: 0.16 dollars
Enter selection: 0
Return recipe:
0. Bandwidth: 10.00 Mbps, Latency: 0.40 ms, Price: 0.18 dollars
1. Bandwidth: 1.00 Mbps, Latency: 0.40 ms, Price: 0.16 dollars
Enter selection: 0
Please pay for the services in the following webpage before you use them:
http://192.122.236.101/new/client/paypal/payment/service/69/2/1414113902560/40/
```

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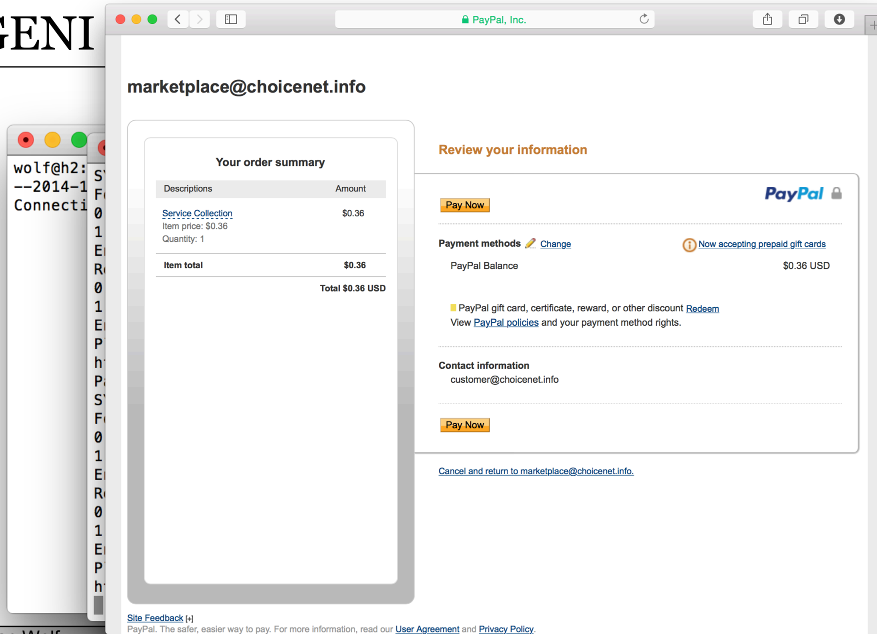
GENI



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GENI Prototype

- Throughput is roughly **10 Mbps**

wolf — wolf@h2: ~ — ssh — 80×24

```
--2014-10-23 21:38:32--  (try:13)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:39:45--  (try:14)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:40:58--  (try:15)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:42:11--  (try:16)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... failed: Connection timed out.
Retrying.

--2014-10-23 21:43:24--  (try:17)  http://10.10.1.1:8080/sample.mp4
Connecting to 10.10.1.1:8080... connected.
HTTP request sent, awaiting response... 200 OK
Length: 73516259 (70M) [video/mp4]
Saving to: `sample.mp4.1'

31% [===========>                          ] 23,193,891  1.14M/s  eta 43s
```

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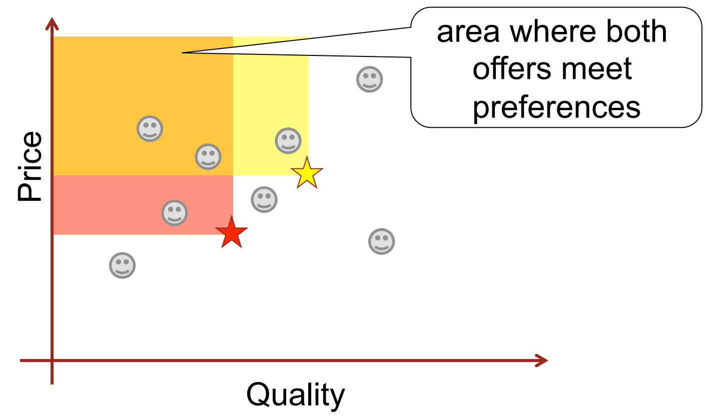
Market Interactions

- **Competing offer** (same or different provider)



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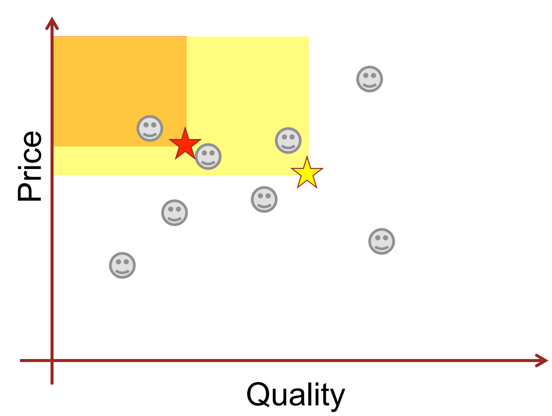
Market Interactions

- Red offer **strictly worse** than yellow



Market Interactions

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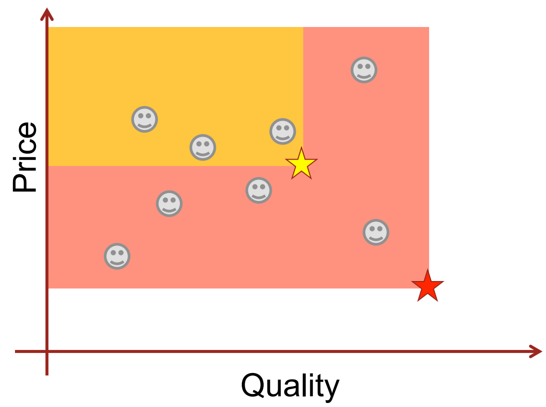
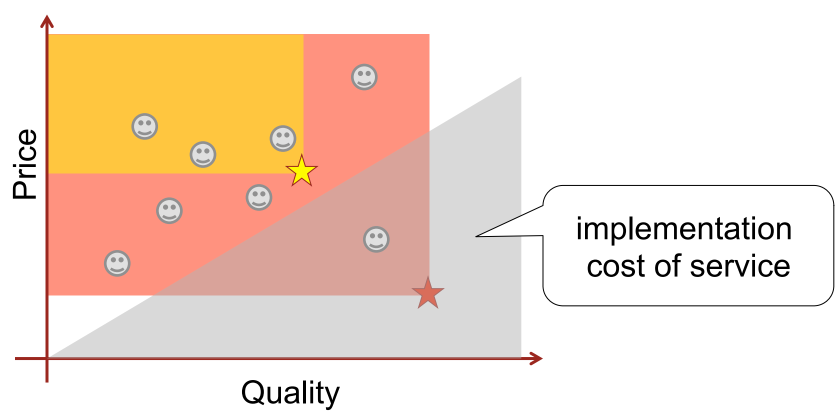


Market Interactions

- Red offer **strictly better** than yellow
  - But may not be feasible due to **cost**



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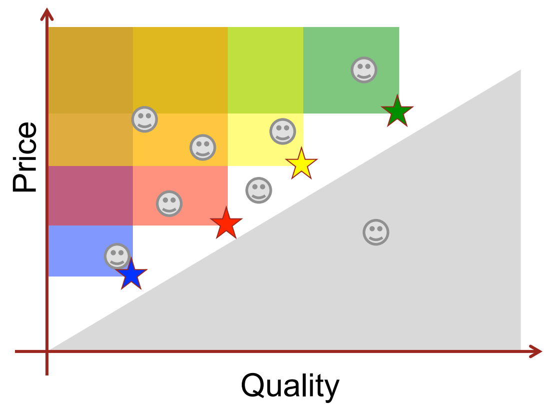
Market Interactions

- Offers will be along **cost constraints**



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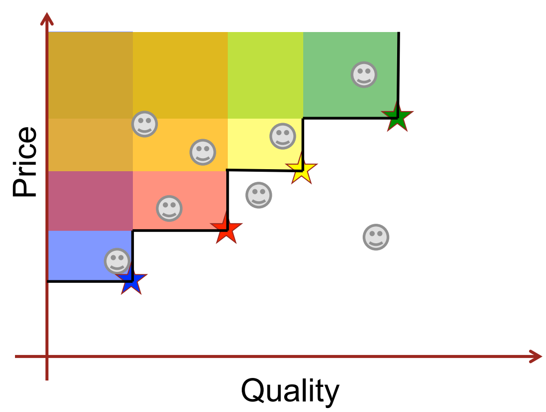
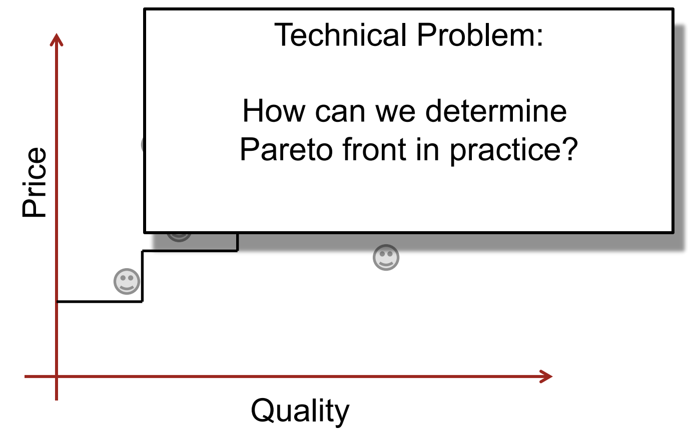
Market Interactions

- Offered summarized in **Pareto front**



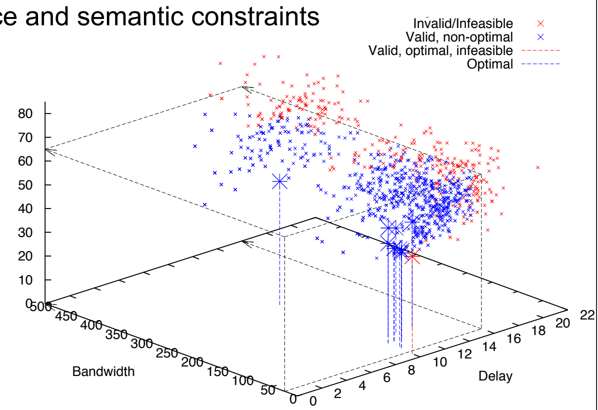
Market Interactions

- Offered summarized in **Pareto front**



Planning Example

- Search for **service compositions**
  - Matches customer requirements
  - Considers performance and semantic constraints
- Example:
  - Three metrics
  - Many candidate paths (1249)
  - **Few Pareto optimal paths** (11)
- Limited choices offered to end-user
  - Clustering of similar offers



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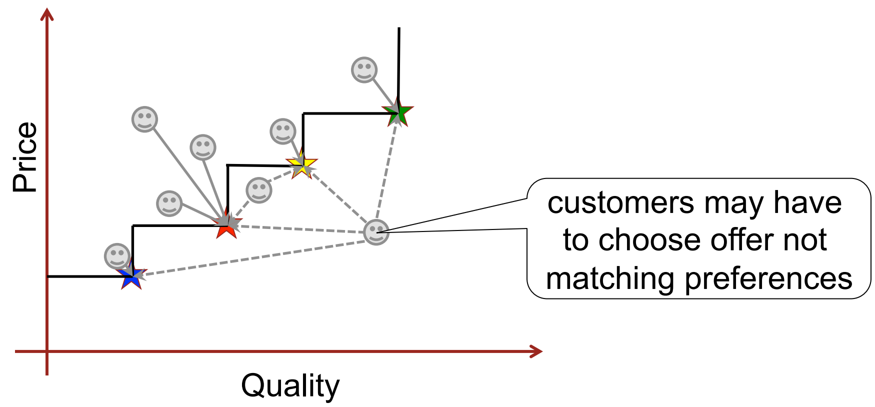
Market Interactions

- Customers choose offer “**close**” to preference



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Simulations

- We want to track market over time
- **Agent-based simulation**
  - **Iterative** process
    - Provider places offer in market
    - Costumers choose one offer (or none)
    - Providers find out what offer was purchased
    - Providers update their offer
  - **Metrics**
    - Price
    - Quality
    - Profits

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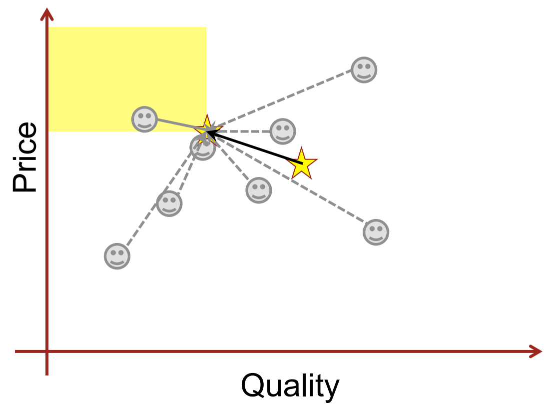
Provider Strategies: Monopoly

- Provider can **increase price** / **lower quality**
  - Customers have no choice other than to drop out



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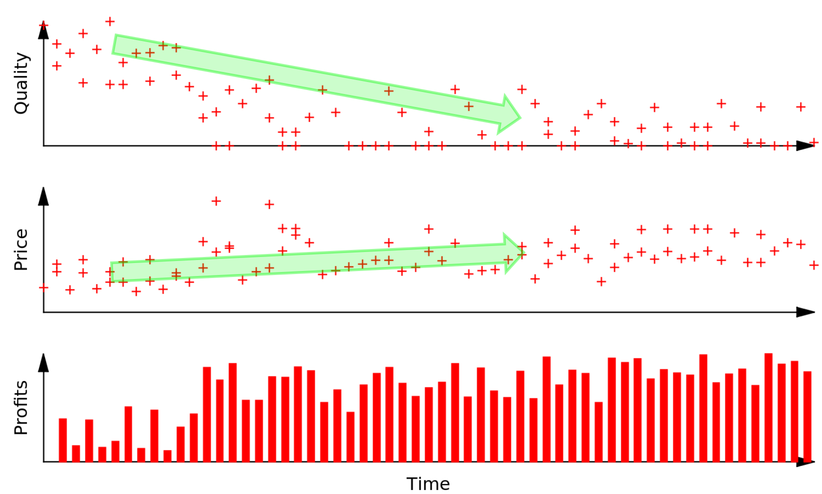
Simulation Results: Monopoly

- Monopoly enables **exploitation of customers**



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Provider Strategies

- Duopoly
  - **Second provider** can compete on price or quality
- Competition
  - Provider may have **multiple offers** in market
- What do we expect?
  - Multiple, competing offers close to cost
  - Profits drop due to "**race to the bottom**"

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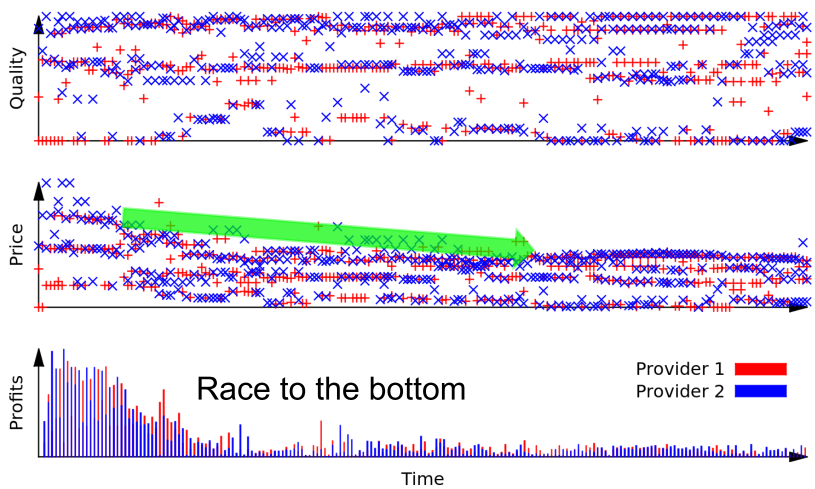
Simulation Results: Duopoly

- Duopoly leads to **reduced profits**



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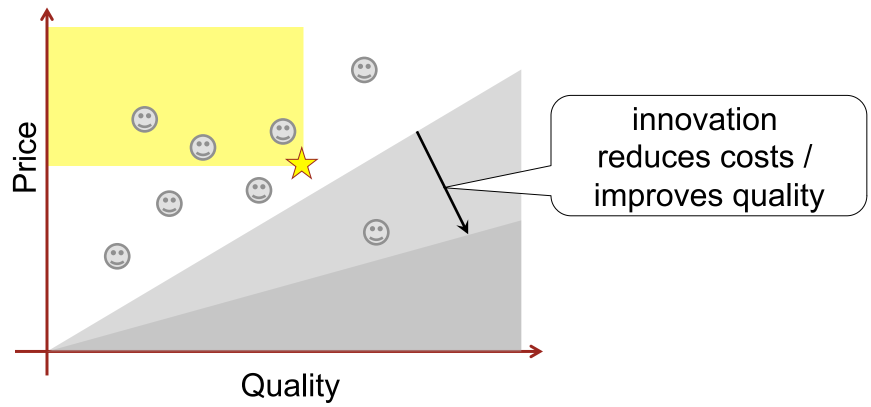
Provider Strategies

- **Innovation** enables new offers, profits



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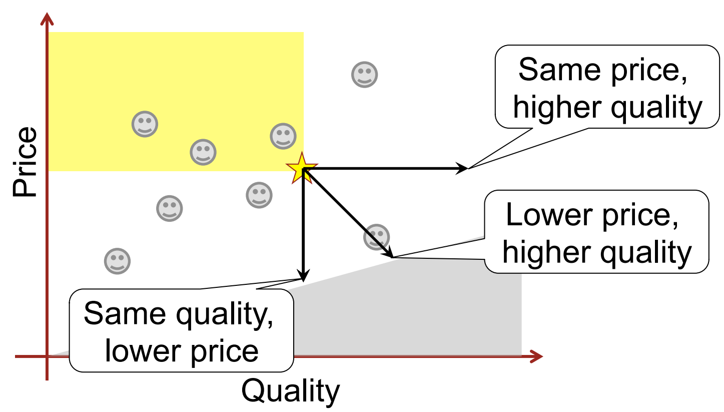
Provider Strategies

- Provider can **improve cost** and/or **quality**



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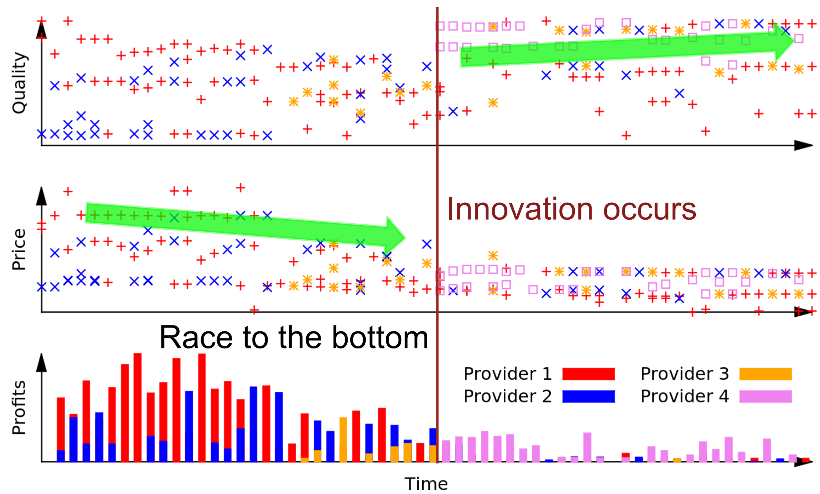
Simulation Results: Oligopoly

- Innovation gives Provider 4 **more profits**



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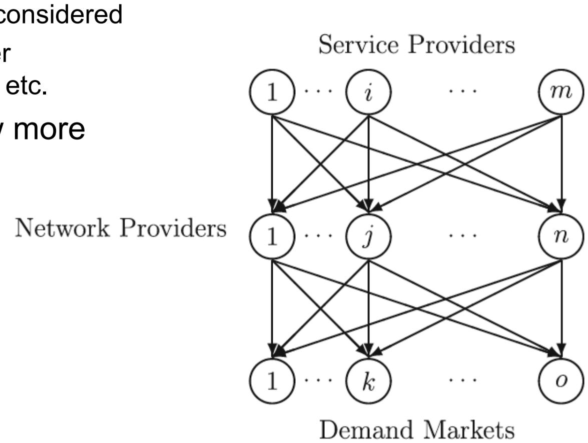
Economic Models

- We have also studied economics more formally
  - **Game theory model** of competition among providers
  - **Price and quality** considered
  - Extensions consider **contract duration**, etc.
- If you want to know more
  - Ask the **experts**:
    - Prof. Nagurney
    - Sara Saberi
    - Michelle Dong



ChoiceNet Economics Summary

- **Competition is good** for consumers
  - Lower cost
  - Higher quality
  - More offerings close to preference
- Providers need to work harder
  - Profits go to **innovative providers**
  - Dynamics require adaptation of offers
- Real world much **more complex**
  - Re-sale of services, changing preferences, etc.
  - Need additional simualtions

Conclusions

- **Economic concerns** critical for new Internet architectures
  - Technologies need to enable economic interactions
- **Economy plane** can enable markets for network services
  - Competition leads to innovation
  - Dynamic contracts at any time scale
- **ChoiceNet project** is developing economy plane
  - Users can choose from competing services
  - Network services, contracts, marketplaces
  - Enabling technologies for economy plane
- Our results show that economy plane is **feasible**
  - Prototype system on GENI
  - Economic simulations show rewards for innovative providers
- When developing new technology, **do not forget economics**!

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Papers for More Information

- **Architecture**:
  - Tilman Wolf, James Griffioen, Kenneth L. Calvert, Rudra Dutta, George N. Rouskas, Ilia Baldine, and Anna Nagurney. ChoiceNet: toward an economy plane for the Internet. *ACM SIGCOMM Computer Communication Review*, 44(3):58–65, July 2014.
- **Economic models**:
  - Sara Saberi, Anna Nagurney, and Tilman Wolf. A network economic game theory model of a service-oriented internet with price and quality competition in both content and network provision. Service Science, 6(4): 229–250, December 2014.
  - Anna Nagurney, Dong Li, Tilman Wolf, and Sara Saberi. A network economic game theory model of a service-oriented internet with choices and quality competition. *NETNOMICS: Economic Research and Electronic Networking*, 14(1-2):1–25, November 2013.
  - Anna Nagurney and Tilman Wolf . A Cournot-Nash-Bertrand game theory model of a service-oriented internet with price and quality competition among network transport providers. *Computational Management Science*, pages 1–28, August 2013.

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Thank you!

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