Prototyping an Economy Plane for the Internet

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Tilman Wolf
Department of Electrical and Computer Engineering
University of Massachusetts Amherst

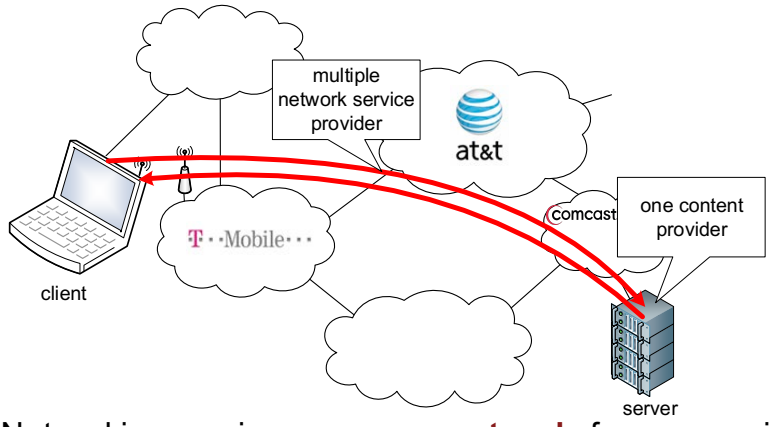
Services in the Internet

- 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

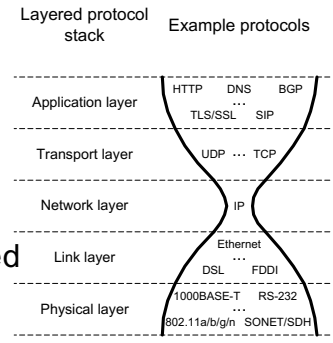
- **Example**: access web page
  - One content provider, **multiple network service providers**



- Networking requires **common protocols** for communication

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 technologies** are being developed
  - New communication paradigms
  - New networking protocols



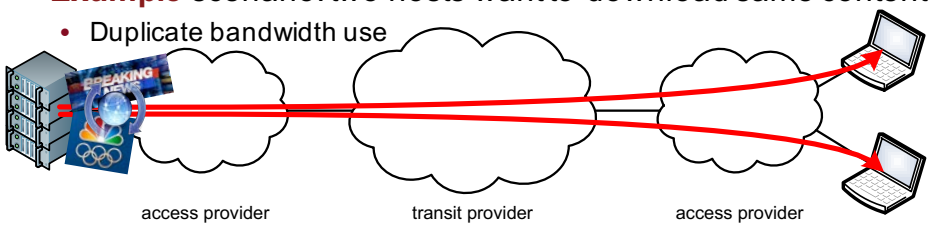
- Thesis of my talk: "**Innovation challenge in Internet is not only technical problem, but also economic problem.**"
  - Focus on network services

Outline

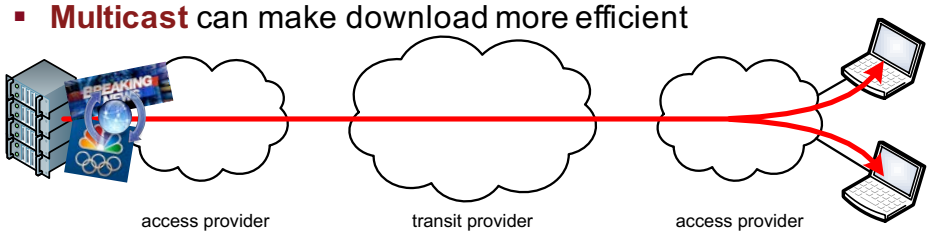
- Introduction
- **Challenges**
  - **Problems with economics in current Internet**
- Economy plane for the Internet
  - ChoiceNet project
  - Competition and Innovation
- GENI implementation of economy plane prototype
  - Technologies
  - Economics
- Conclusions

Economic Deployment Problem: Multicast

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

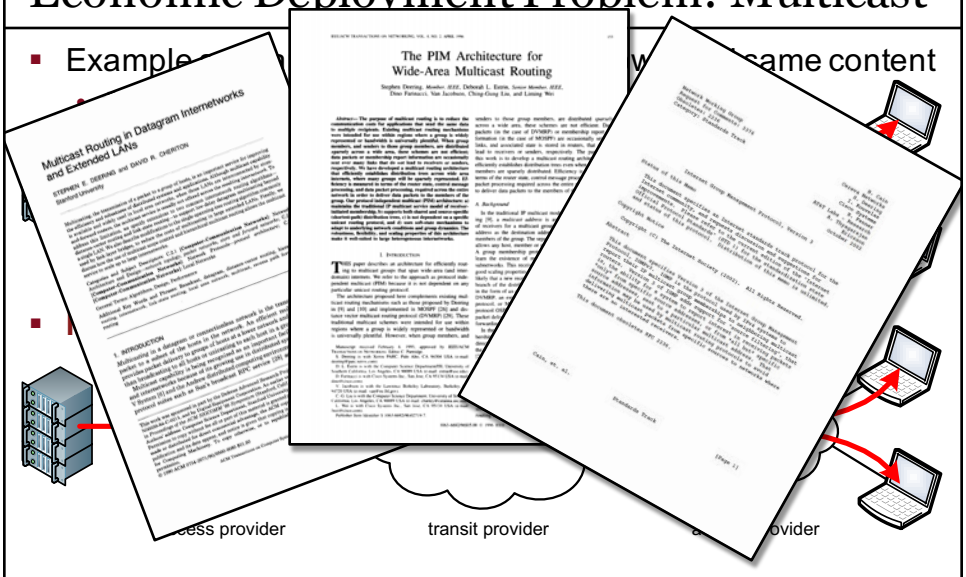


- **Multicast** can make download more efficient



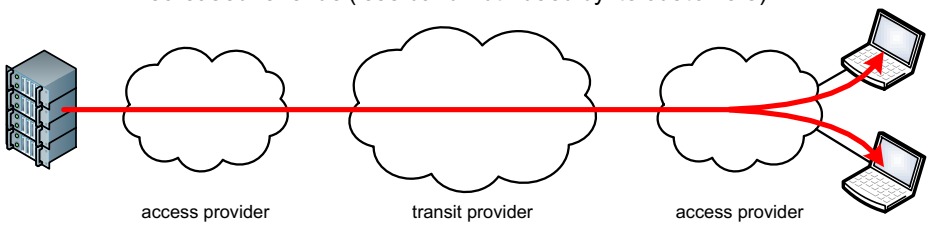
Economic Deployment Problem: Multicast

- Example
- same content



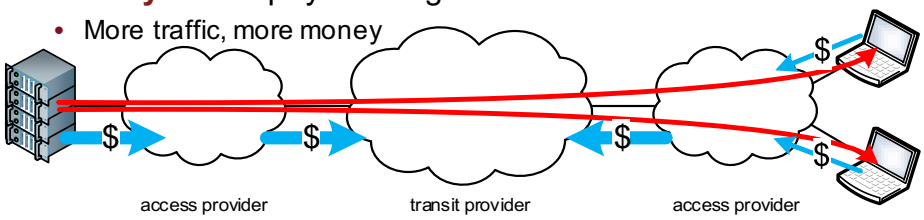
Economic Deployment Problem: Multicast

- 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)

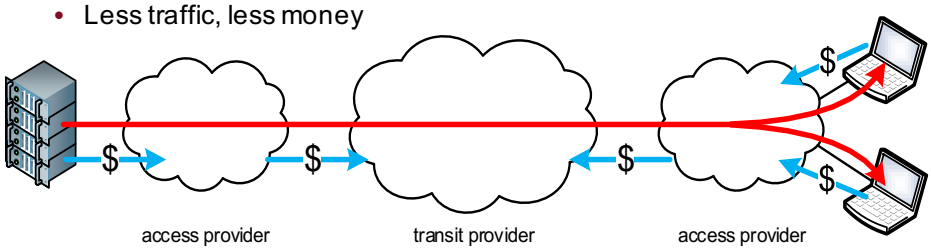


Economic Deployment Problem: Multicast

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



  - Less traffic, less money



Economic Deployment Problem: Multicast

- **de support**

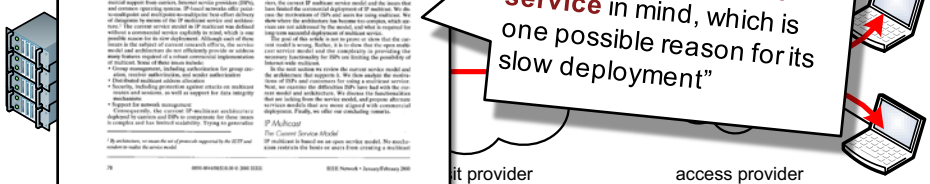
Deployment Issues for the IP Multicast Service and Architecture

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 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"

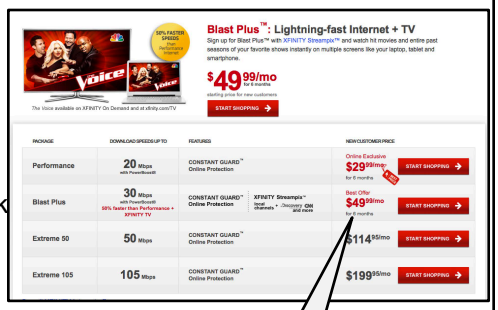


Charging Models in Internet

- Many different **charging models** for network services
  - FCC 15-24 Open Internet ruling
    - **All traffic equal**: no blocking, throttling, preference
  - Misra: Routing Money, Not Packets (ACM CACM)
    - Packets have **different economic values**
    - Treating all packets equal does not align with reality
    - "[Treating all packet as equal] has the potential to slow down innovation on the Internet, because the implication is that any kind of application that requires something more than best-effort service has a barrier to entry placed by regulations."
  - Odlyzko: **smart pricing** (Smart Data Pricing, Wiley)
    - Pricing network services may have pitfalls
- Our project: technology to enable **any** charging model
  - No advocacy for one specific one
  - General "**economy plane**" to make economic relationships explicit

Economics in Today's Internet

- End-users:
  - **Long-term contracts** with single provider
  - **No practical choice** for user
    - Cannot easily switch providers
    - Cannot choose services
  - **No control** over path in network
- Providers:
  - **Long-term peering agreements**
  - Limited control over network paths
- Can we enable choice and competition?
  - Control over traffic along entire path
- Dynamic **"Economy Plane"**
  - Multiple providers
  - **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**
- GENI implementation of economy plane prototype
  - 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, …

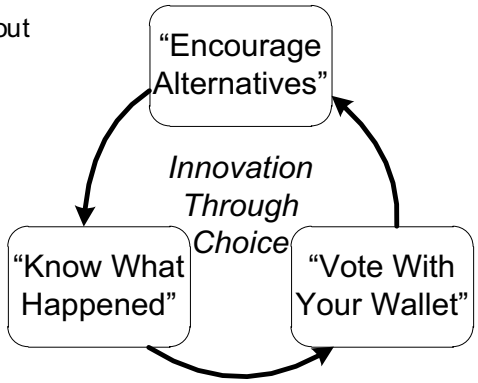






Principles for ChoiceNet

- 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



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

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

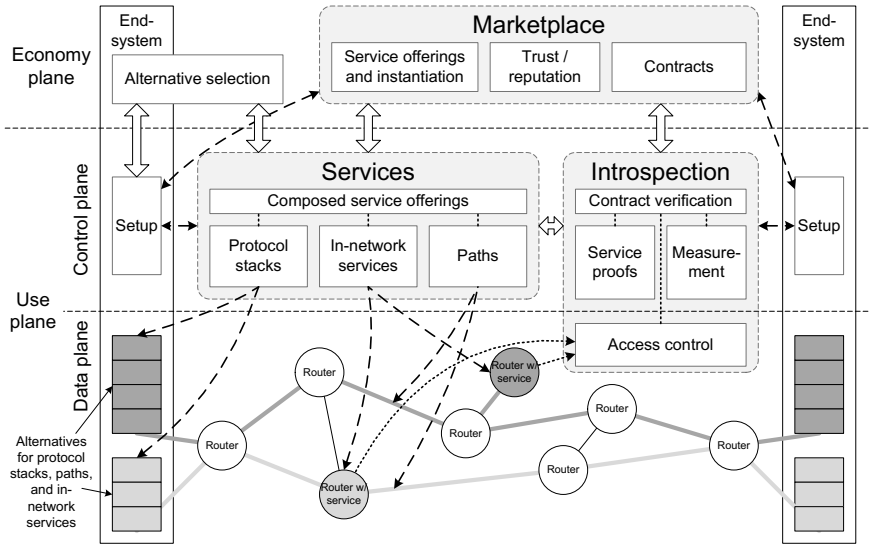
Concept 2: Contracts

- 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

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



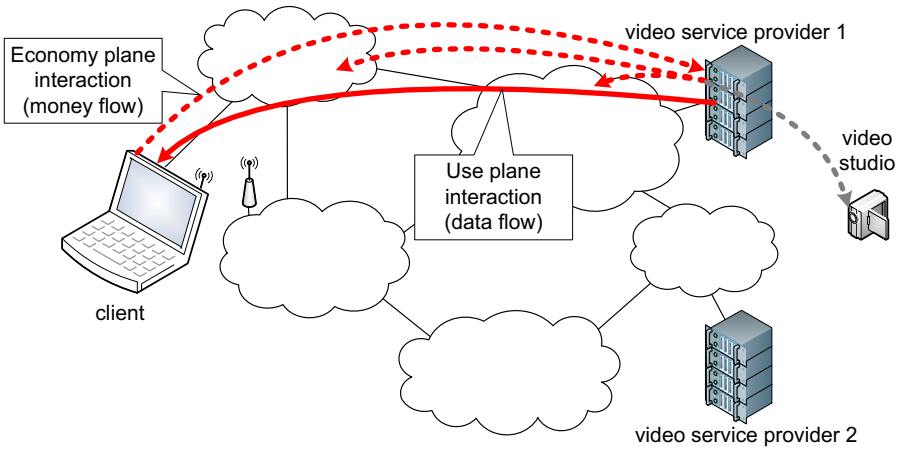
Vision: Movie Streaming Example

- 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

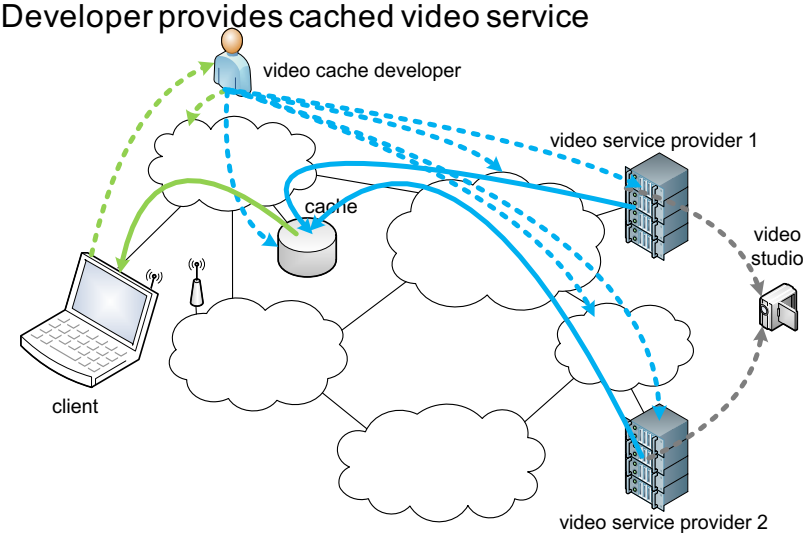
Movie Streaming Example

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



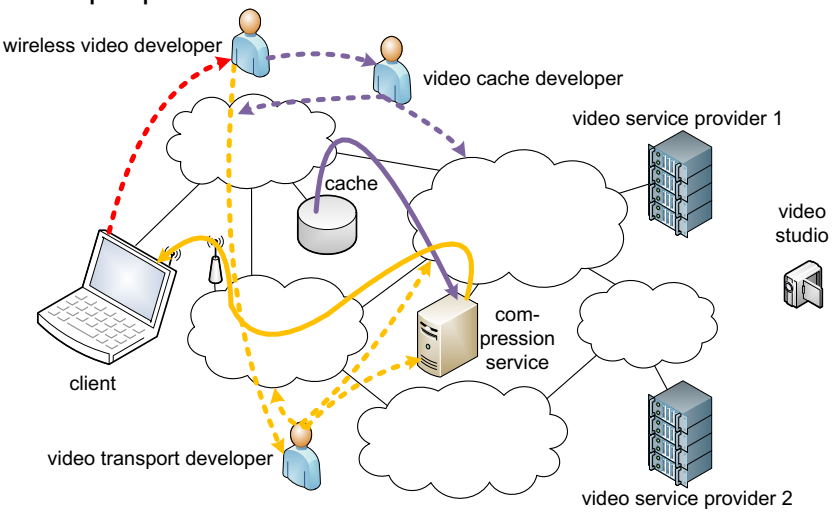
Movie Streaming Example

- Developer provides cached video service



Movie Streaming Example

- Developer provides services without infrastructure



UMassAmherst

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**

UMassAmherst

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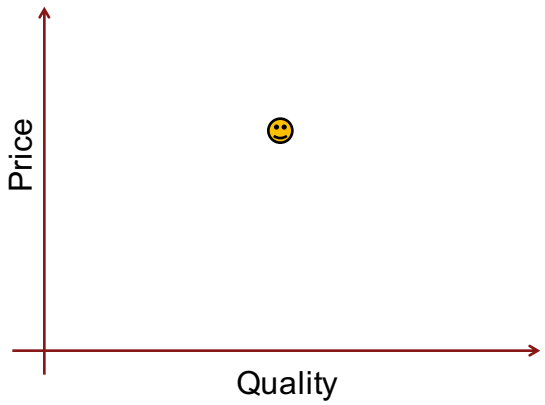
- **GENI implementation of economy plane prototype**
  - **Technologies**
  - **Economics**
- Conclusions

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



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Market Interactions

- Market consists of **many customers**

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Market Interactions

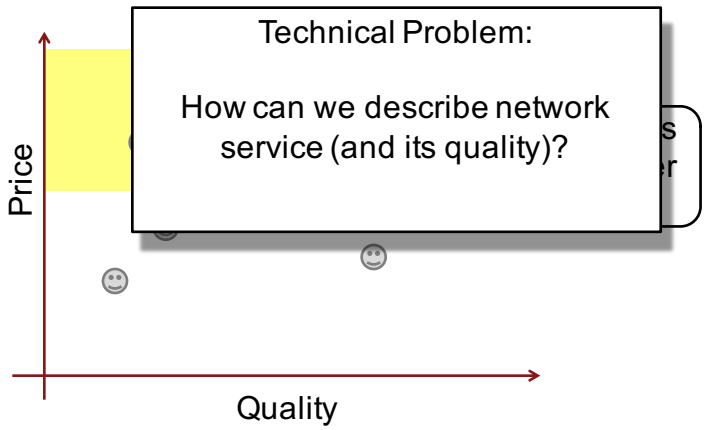
- Providers do **not** know preferences a priori

Market Interactions

- Providers **offers service** in marketplace

Market Interactions

- Offer meets preference of **some customers**

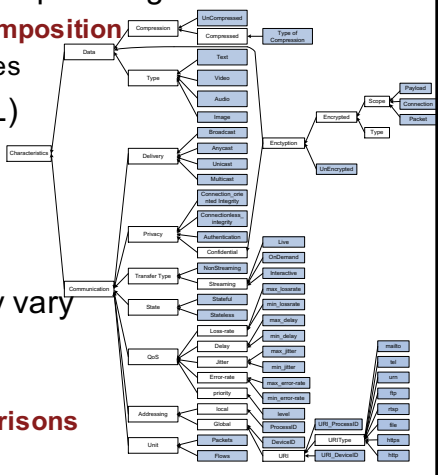


ChoiceNet Service Description

- 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

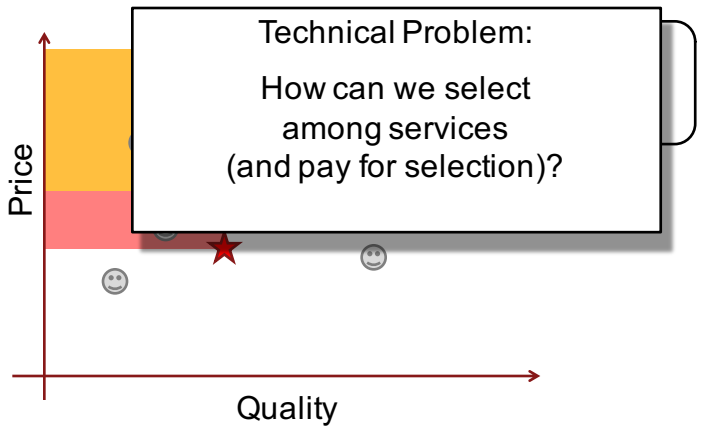
ChoiceNet Service Description

- 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**



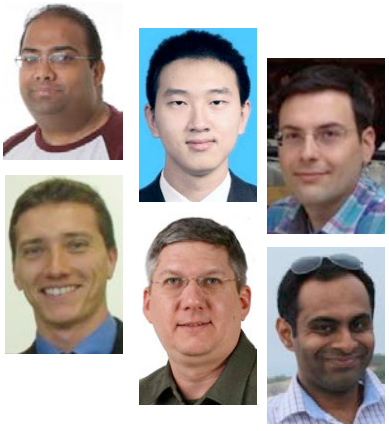
Market Interactions

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



ChoiceNet Prototype

- **GENI-based prototype implementation**
  - "UMass" prototype uses **Software-Defined Networks** (SDN)
  - "UKy" prototype uses **source-routing in IP**
- SDN-based prototype focus of this talk
- Acknowledgements:
  - Hussam Nasir, UKY
  - Xinming Chen, UMass
  - Onur Ascigil, UKY
  - Thiago Teixeira, UMass
  - Charles Carpenter, UKY
  - Abhishek Dwaraki, UMass

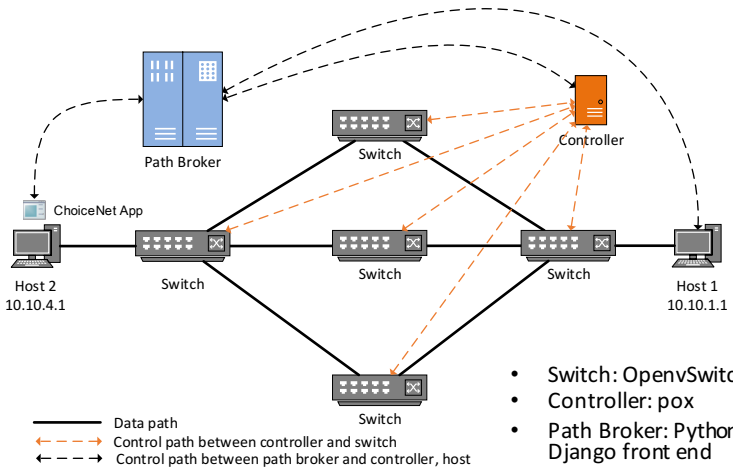


SDN-Based Prototype on GENI

- SDN implements per-flow routing
- **Forwarding Service**
  - SDN-enabled switches, accepting setup commands from Controller
- **Path Service**
  - Controller
    - Computes Intra-AS routes
    - Sends advertisements to Path Broker
  - Path Broker
    - Computes Inter-AS routes
    - Has a web front-end for payments
- **ChoiceNet-enabled application**
  - Network traffic intercepted using netfilter
  - Separate ChoiceNet app as interface between user and path broker

SDN-Based ChoiceNet Operation

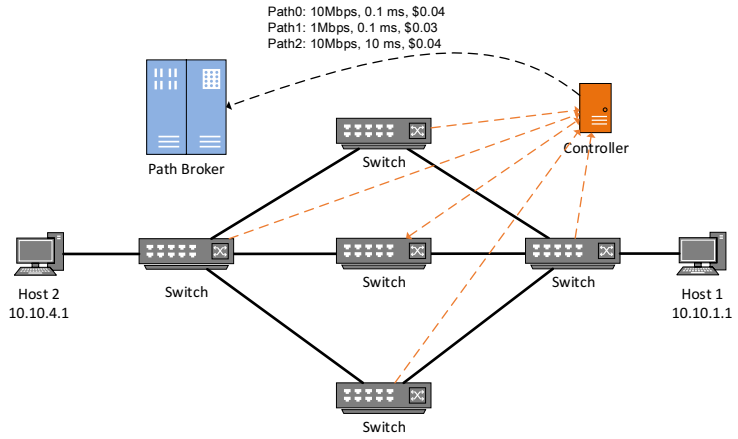
- **Path Broker** at core of interactions



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

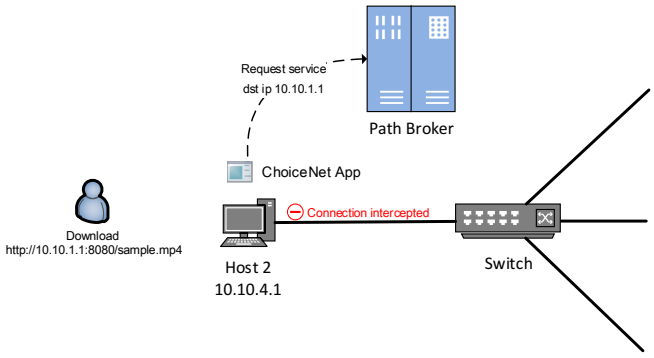
SDN-Based ChoiceNet Operation

- **Controller** detects paths and advertises them



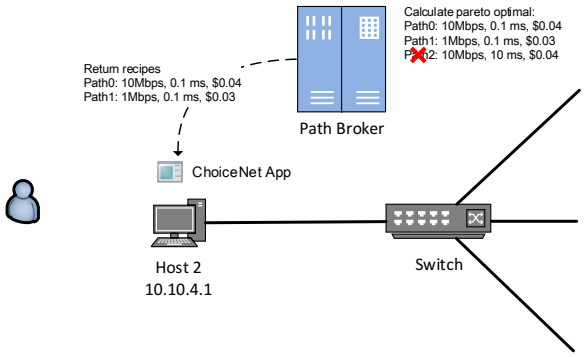
SDN-Based ChoiceNet Operation

- User/**application** starts a connection
  - OS intercepts connection request
  - ChoiceNet App request path from path broker



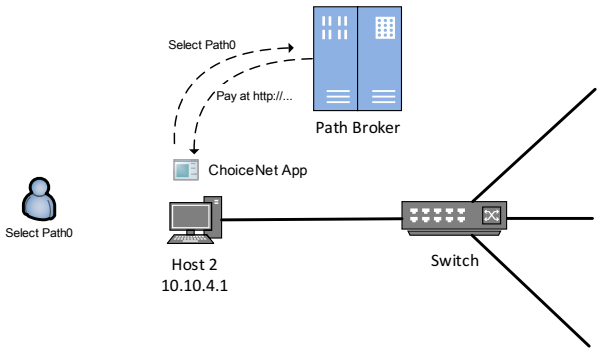
SDN-Based ChoiceNet Operation

- Path broker calculates **Pareto-optimal paths**
  - Returns offers to ChoiceNet app



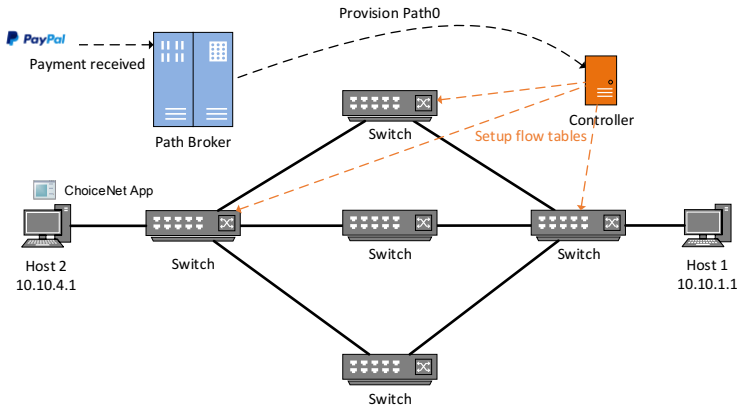
SDN-Based ChoiceNet Operation

- User/application makes **path selection**
  - Path broker requests payment



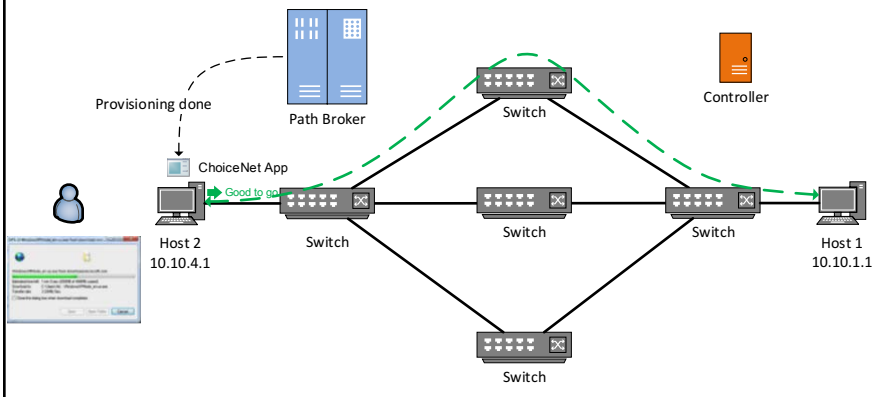
SDN-Based ChoiceNet Operation

- **Payment** issued via Paypal website
  - After receiving payment, broker provisions path



SDN-Based ChoiceNet Operation

- After provisioning, path broker informs App
  - **Transmission begins**

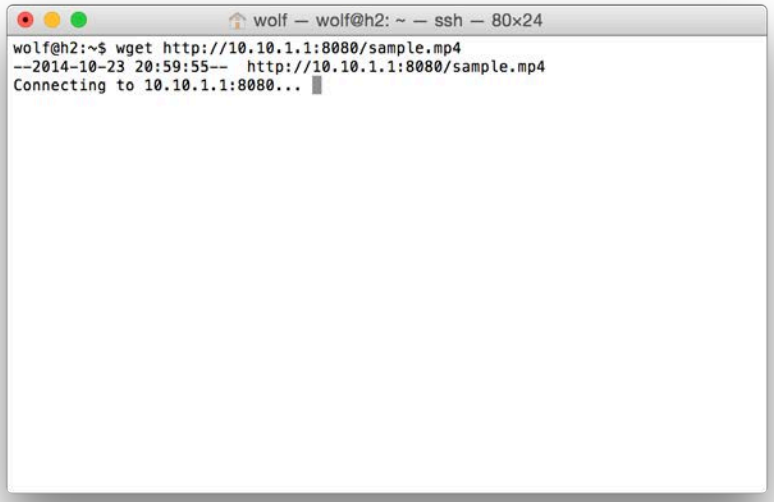


GENI Prototype

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

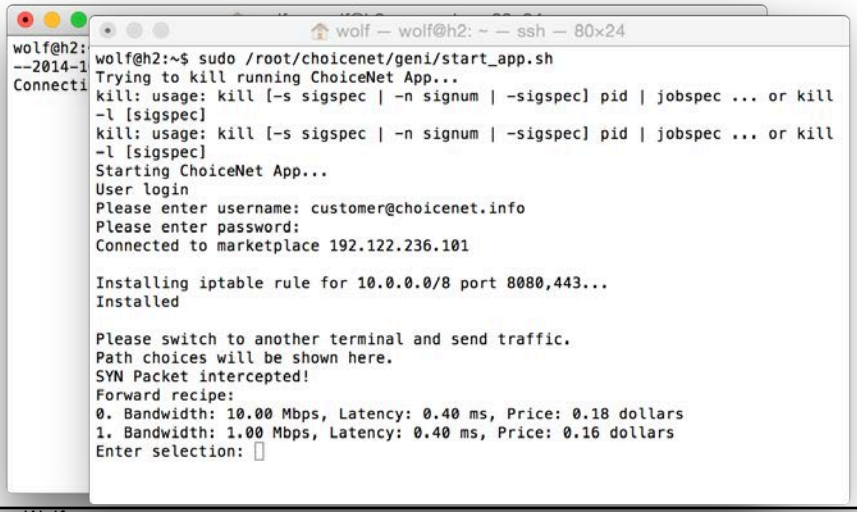
GENI Prototype

- Connection request is **intercepted**



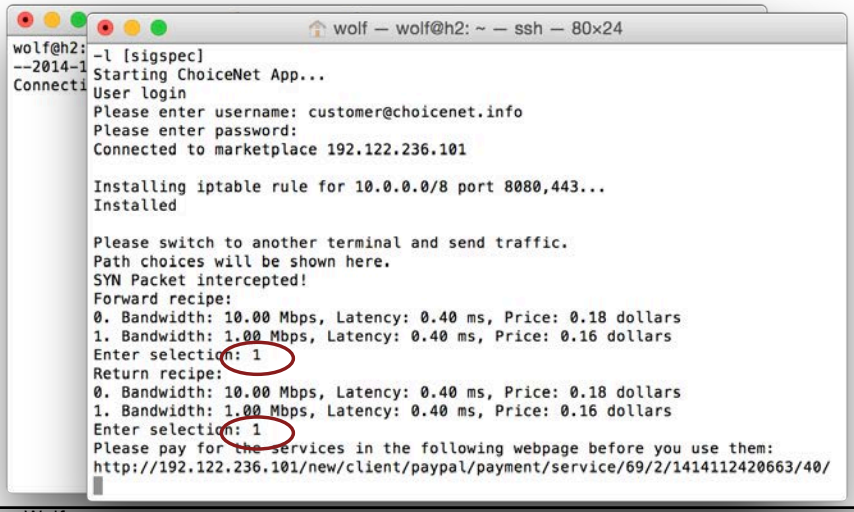
GENI Prototype

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



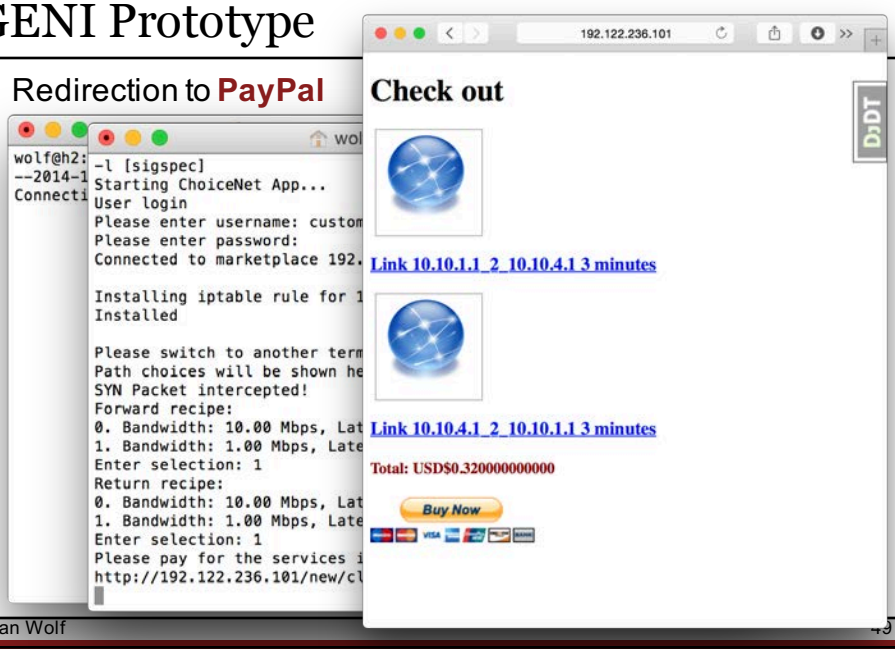
GENI Prototype

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



GENI Prototype

- Redirection to **PayPal**



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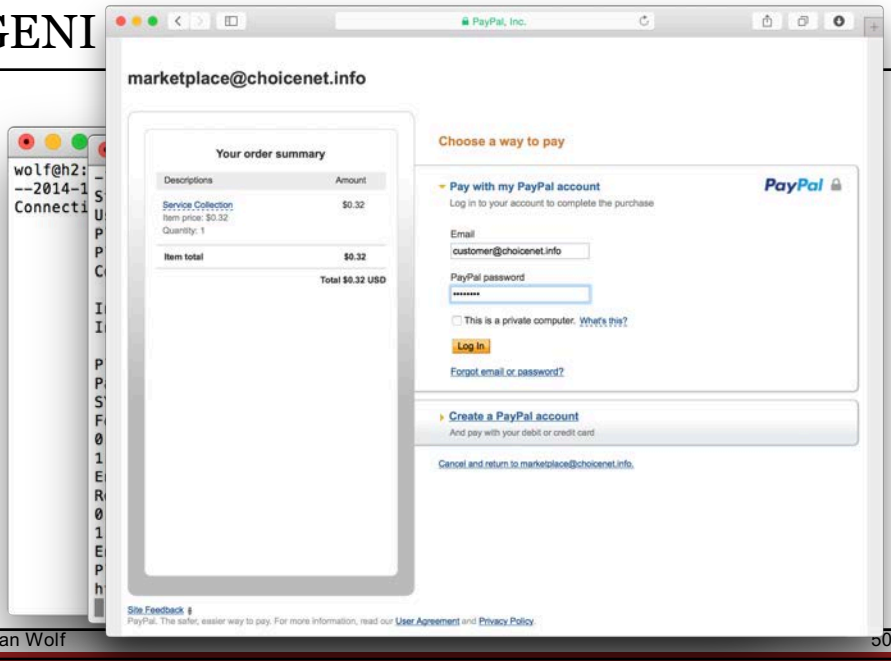

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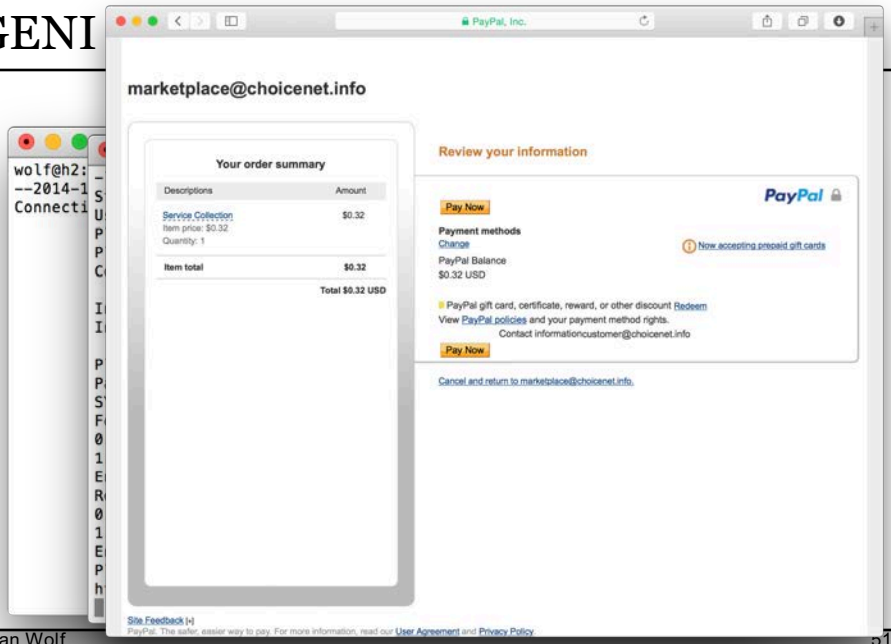
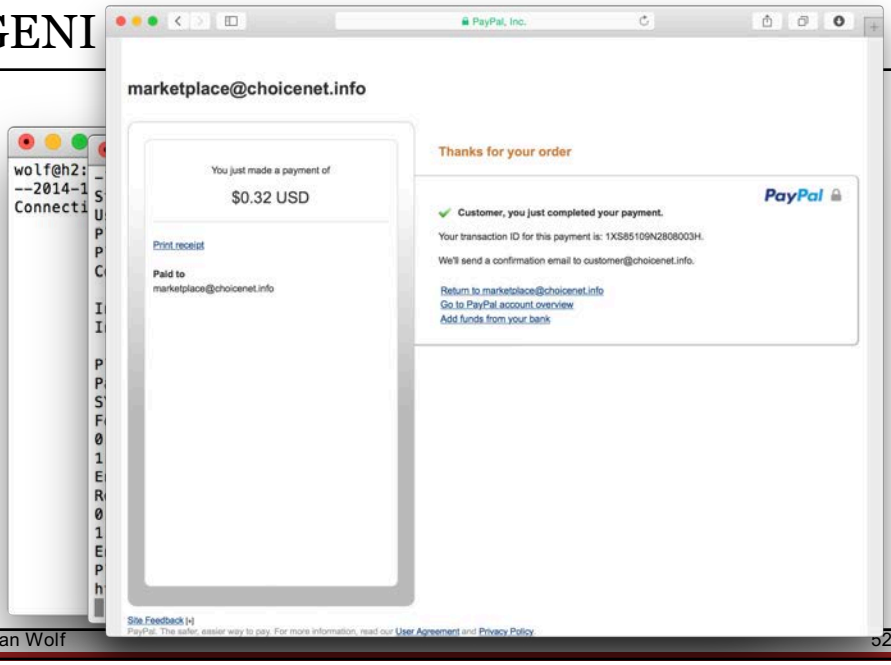
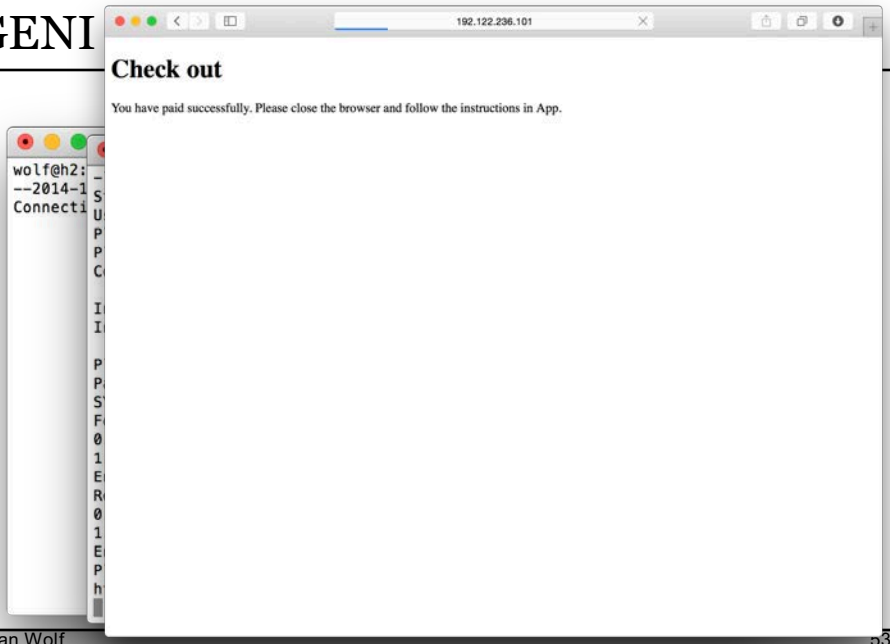

PayPal, Inc.
marketplace@choicenet.info
Your order summary
Descriptions
Amount
Service Collection
Item price: $0.32
Quantity: 1
$0.32
Item total
$0.32
Total $0.32 USD
Review your information
PayPal
Pay Now
Payment methods
Change
Now accepting prepaid gift cards
PayPal Balance
$0.32 USD
PayPal gift card, certificate, reward, or other discount Redeem
View PayPal policies and your payment method rights.
Contact informationcustomer@choicenet.info
Pay Now
Cancel and return to marketplace@choicenet.info.
Site Feedback
PayPal. The safer, easier way to pay. For more information, read our User Agreement and Privacy Policy

GENI

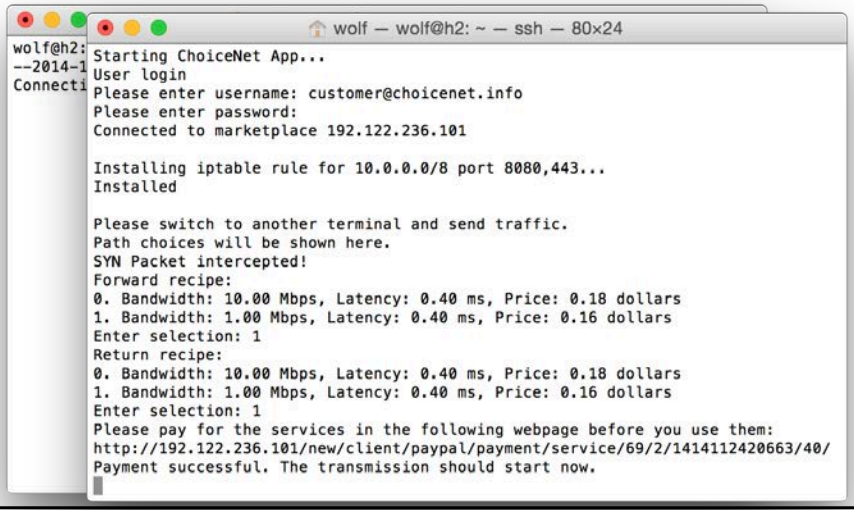

PayPal, Inc.
marketplace@choicenet.info
You just made a payment of
$0.32 USD
Print receipt
Paid to
marketplace@choicenet.info
Thanks for your order
PayPal
Customer, you just completed your payment.
Your transaction ID for this payment is: 1XS85109N2808003H.
We'll send a confirmation email to customer@choicenet.info.
Return to marketplace@choicenet.info
Go to PayPal account overview
Add funds from your bank
Site Feedback
PayPal. The safer, easier way to pay. For more information, read our User Agreement and Privacy Policy

GENI



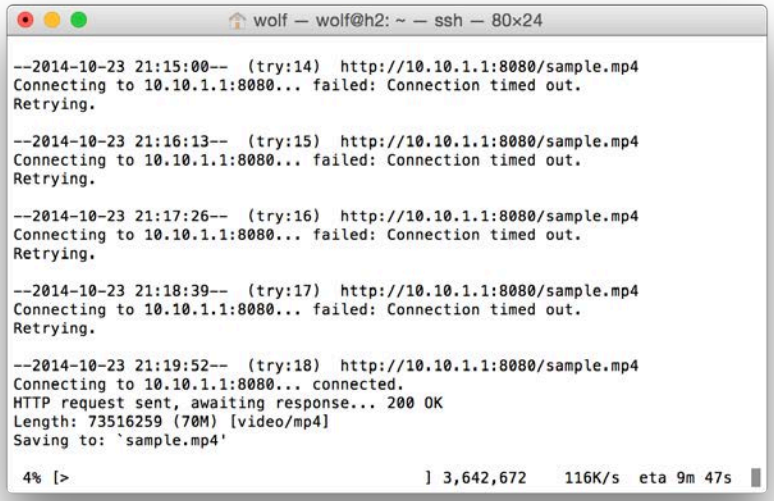
GENI Prototype

- **Successful payment**



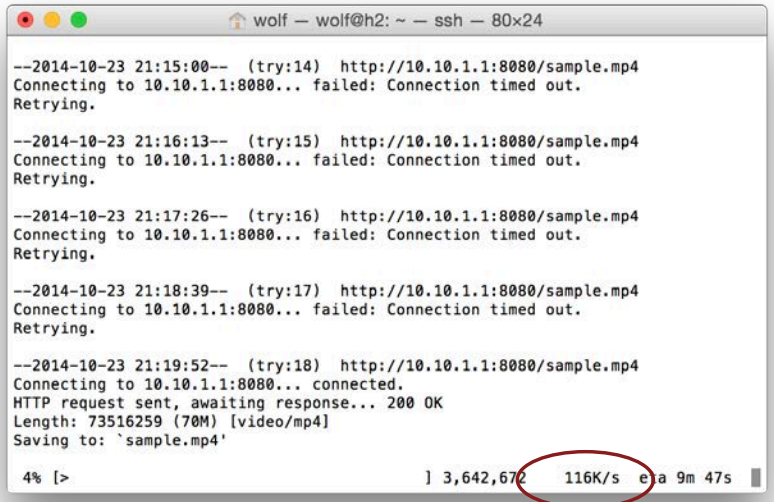
GENI Prototype

- **Transmission starts**



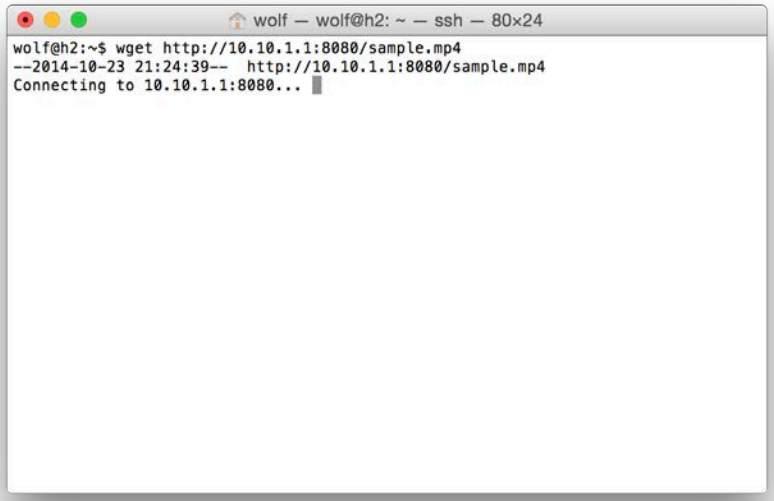
GENI Prototype

- Throughput is roughly **1 Mbps**



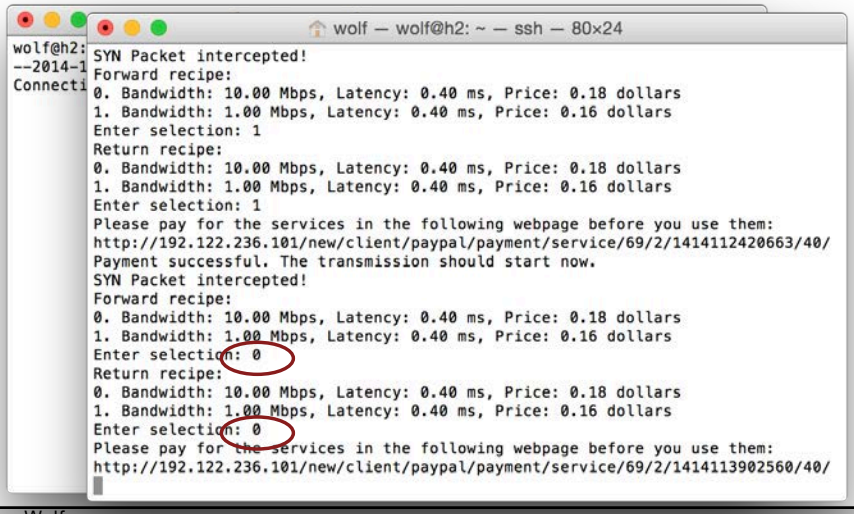
GENI Prototype

- User repeats **exactly same command**

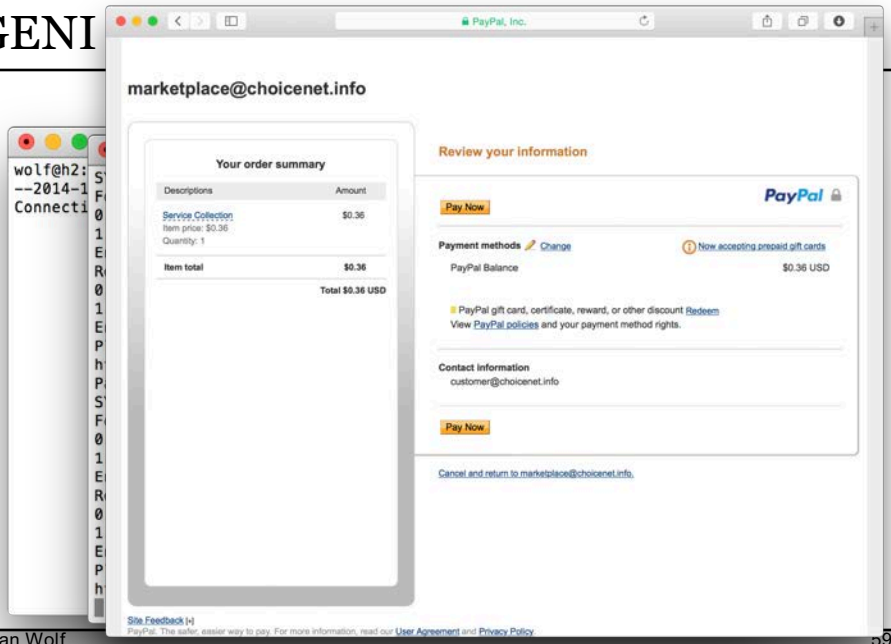


GENI Prototype

- User **chooses 10 Mbps** path

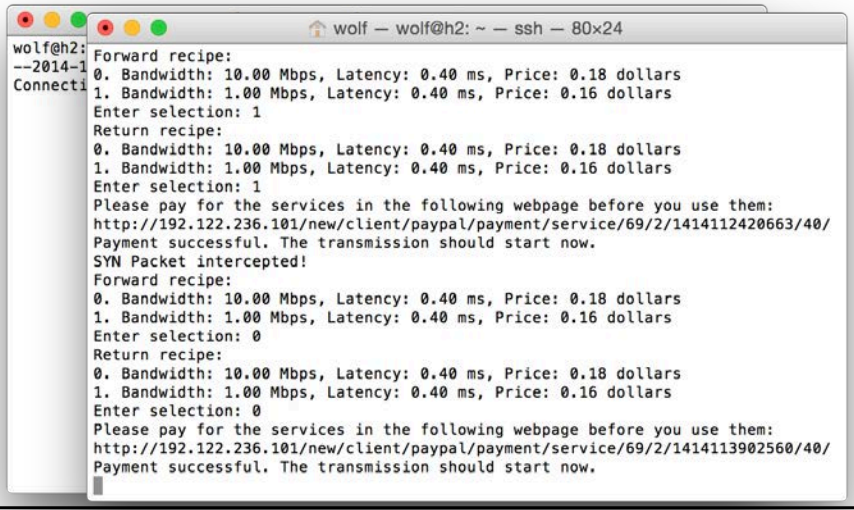


GENI



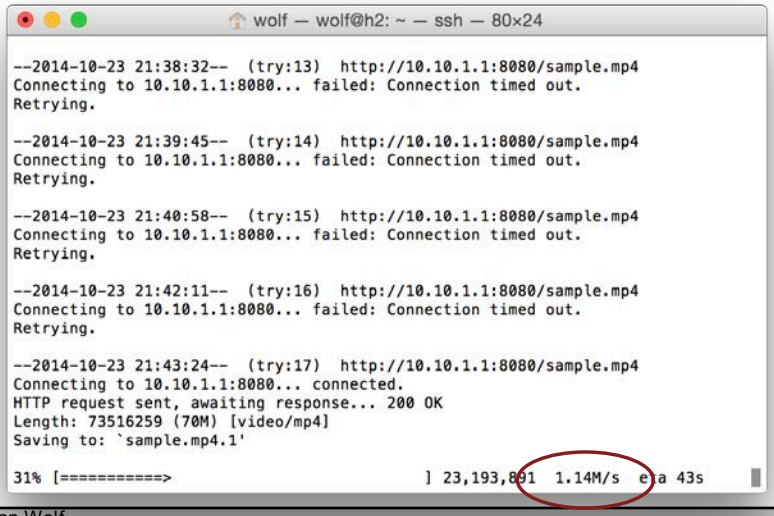
GENI Prototype

- User **pays more** for the higher-quality connection



GENI Prototype

- Throughput is roughly **10 Mbps**

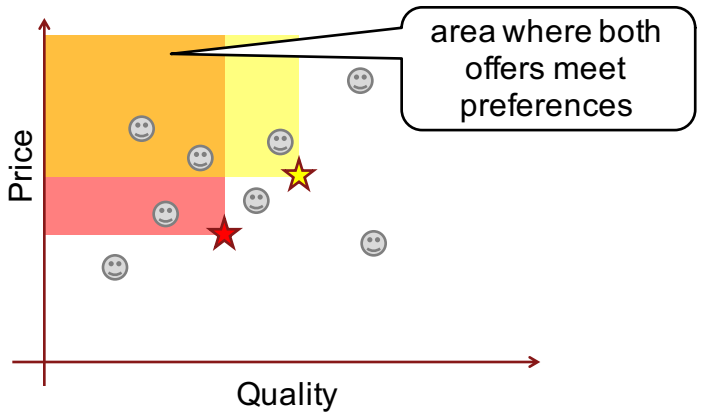


GENI Prototype Summary

- Direct relationship between **network service** and **payment**
  - Higher performance requires higher payment
  - Real payment system (PayPal) used
- **Limitations**
  - Current services are only end-to-end paths
    - More complex services could be constructed
    - ChoiceNet allows processing and storage services
  - No verification mechanism if service was good
    - External measurement to provide “insurance”
  - No escrow for money
    - No recourse for customer
- Prototype demonstrates **feasibility of ChoiceNet**

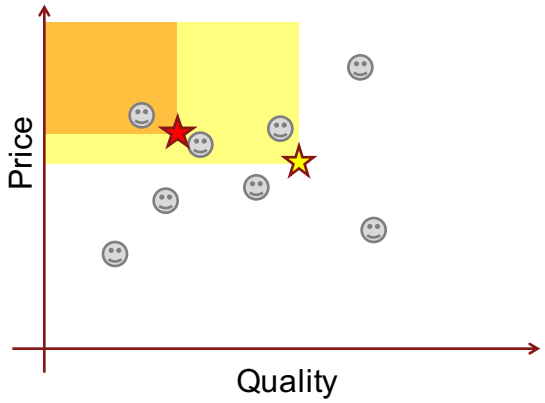
Market Interactions

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



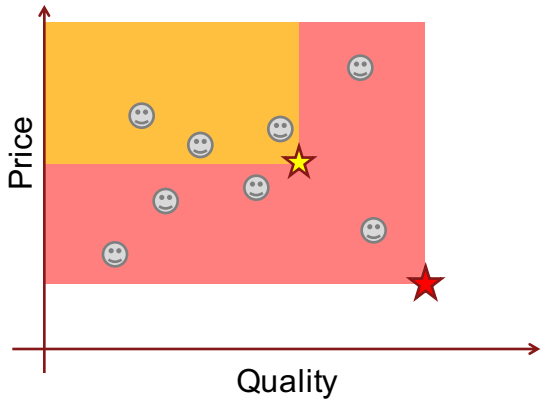
Market Interactions

- Red offer **strictly worse** than yellow



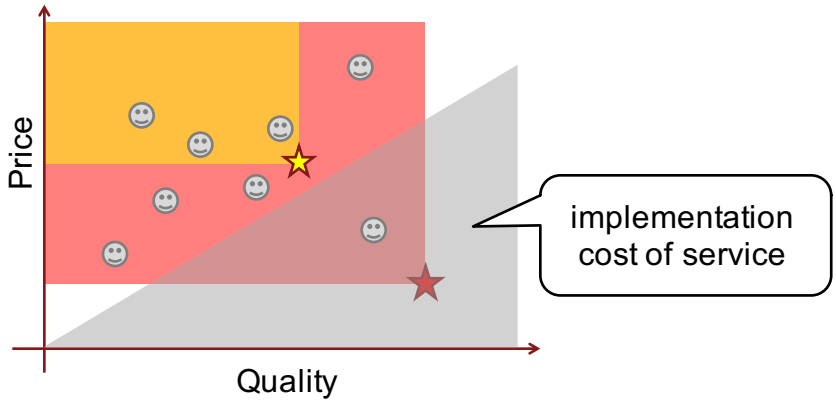
Market Interactions

- Red offer **strictly better** than yellow



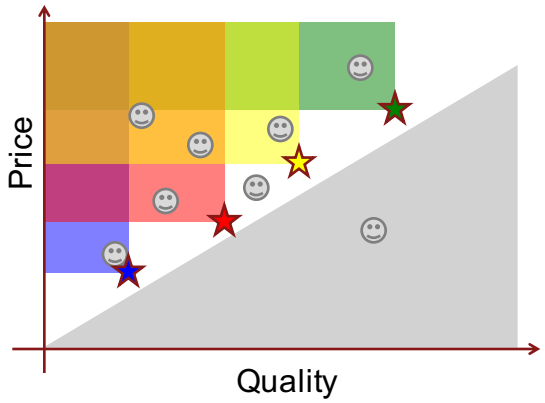
Market Interactions

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



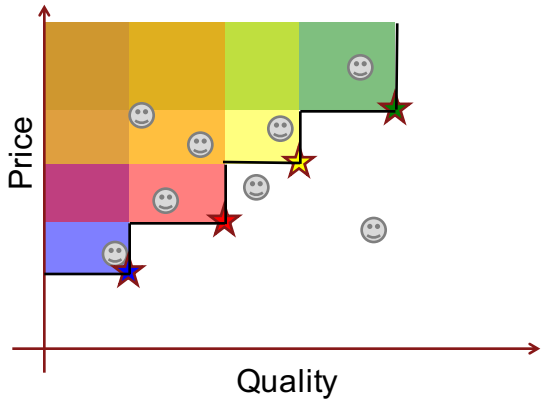
Market Interactions

- Offers will be along **cost constraints**



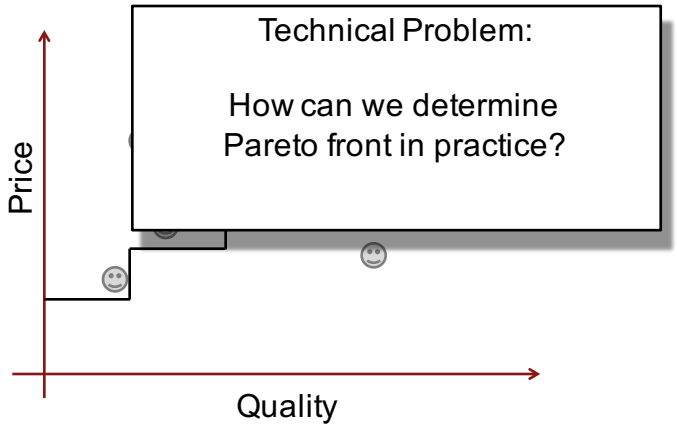
Market Interactions

- Offered summarized in **Pareto front**



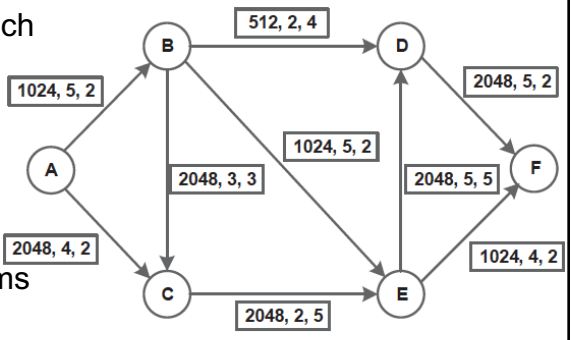
Market Interactions

- Offered summarized in **Pareto front**



Multi-Criteria Path Finding

- **Multiple criteria** for each link or path
  - Bandwidth
  - Delay
  - Cost
  - Reliability
  - Etc.
- Many existing algorithms **weigh criteria a priori**
  - Does not work if customers preferences are unknown
- **A posteriori weighting** requires finding of all paths
  - Only **Pareto-optimal set** of paths is interesting

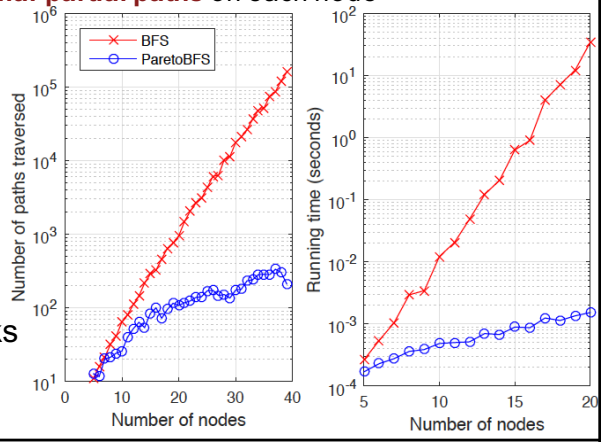


Path list at node F:

p_1 =(A,B,D,F): 512, 12, 8 p_2 =(A,C,E,F): 1024, 10, 9 p_3 =(A,B,E,F): 1024, 14, 6 p_4 =(A,C,E,D,F): 2048, 16, 14	Pareto-optimal path.
p_5 =(A,B,E,D,F): 1024, 20, 11 p_6 =(A,B,C,E,F): 1024, 14, 12 p_7 =(A,B,C,E,D,F):1024, 20, 17	Not Pareto-optimal and discarded.

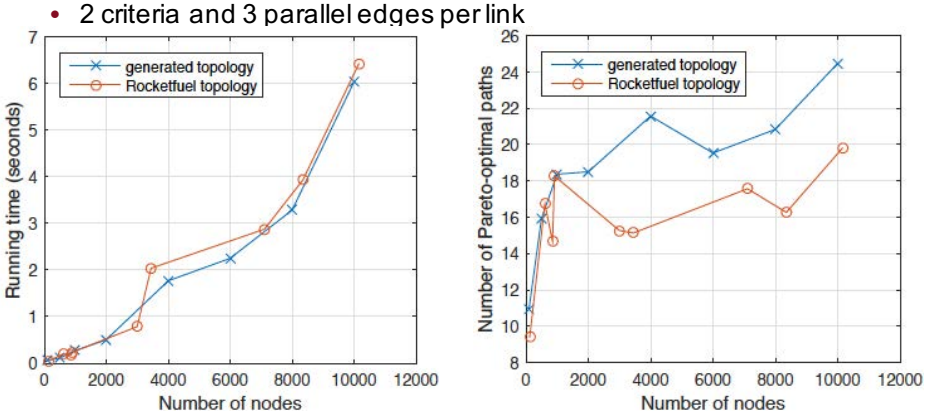
Multi-Criteria Path Finding

- **ParetoBFS algorithm**
  - Breadth-first search
  - **Pruning of non-optimal partial paths** on each node
- Pruning reduces exponential growth in complexity
  - Still maintains all path necessary to find **complete Pareto-optimal set**
- Algorithm can **scale** to very large networks



Multi-Criteria Path Finding

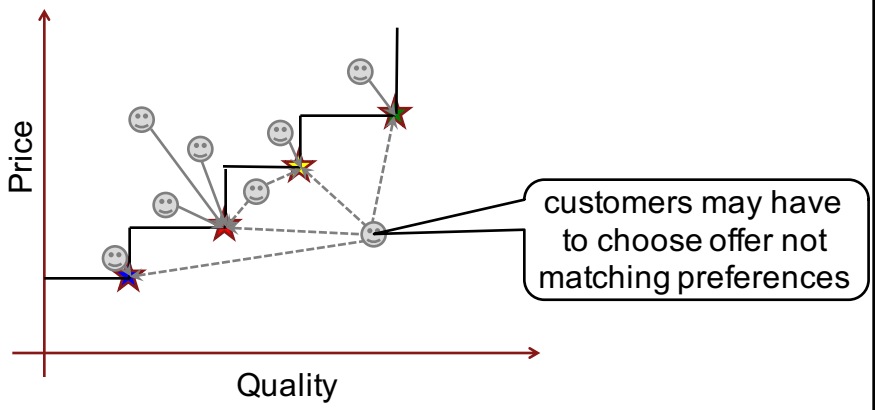
- **Running time** and **number of resulting choices**
  - 2 criteria and 3 parallel edges per link



- Algorithm yields **manageable number of choices**
  - Running time and choices can be reduced by **sampling**

Market Interactions

- Customers choose offer "**close**" to preference

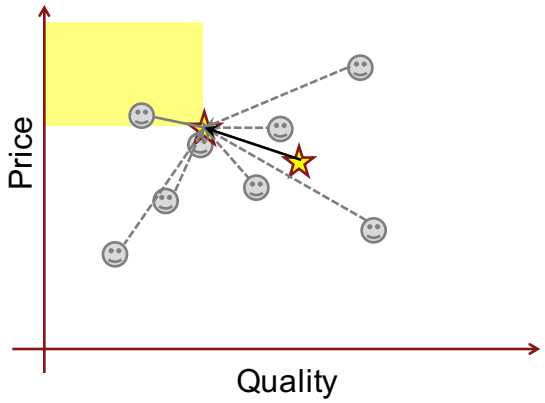


Simulations

- 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

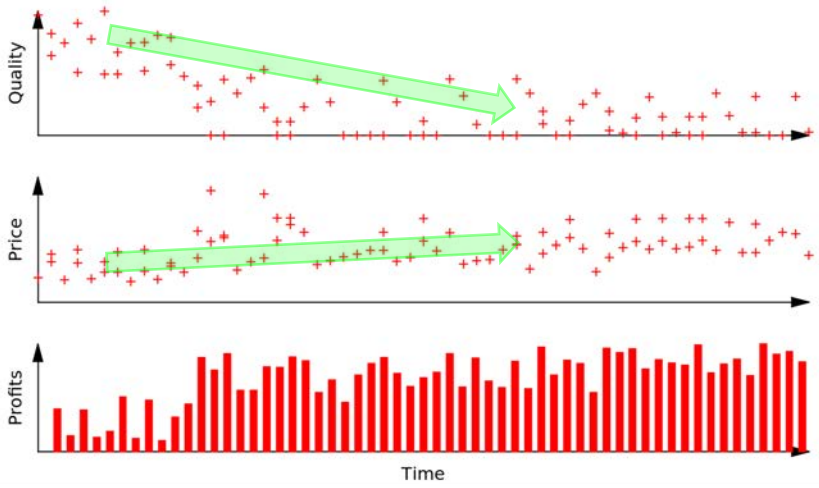
Provider Strategies: Monopoly

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



Simulation Results: Monopoly

- Monopoly enables **exploitation of customers**

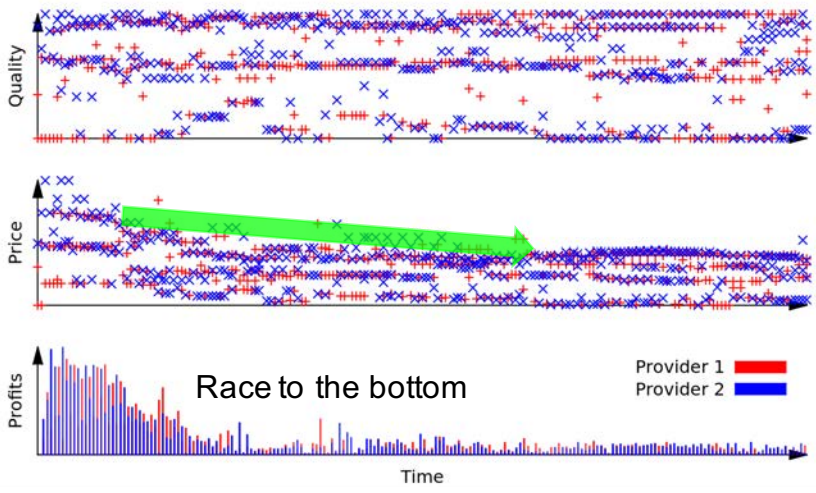


Provider Strategies

- 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**"

Simulation Results: Duopoly

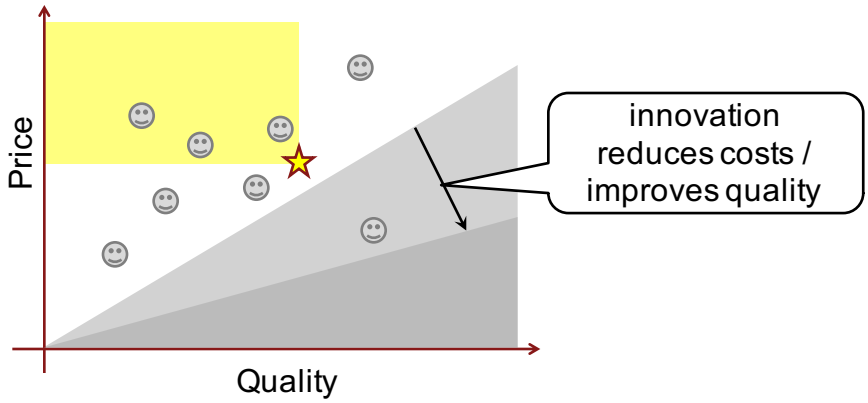
- Duopoly leads to **reduced profits**



UMassAmherst

Provider Strategies

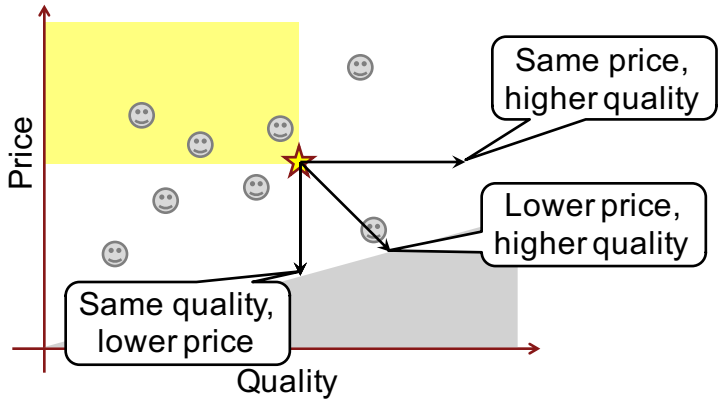
- **Innovation** enables new offers, profits



UMassAmherst

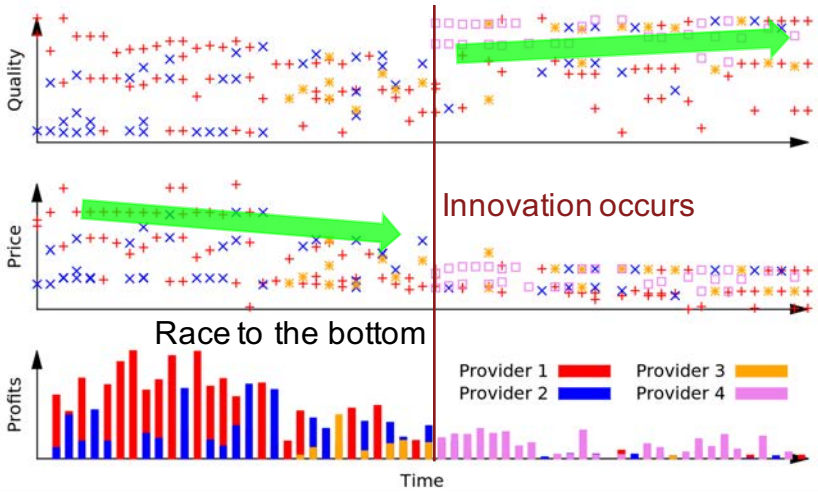
Provider Strategies

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



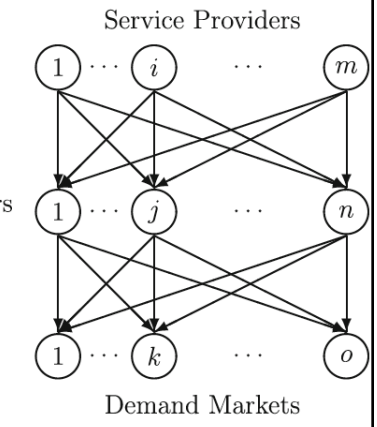
Simulation Results: Oligopoly

- Innovation gives Provider 4 **more profits**



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.
- Results show **stability**, development of prices, effects of competition
- Applied economic models to **specific scenarios**
  - Delay-tolerant services in **rural Colombia**
  - Models assess profitability of providers



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 simulations

Conclusions

- **Economic concerns** critical for new Internet architectures
  - Technologies need to enable economic interactions
- **Baseline fairness** is important for access
  - Competition and innovation can still take place in private IP networks
- **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**!

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.
- **Path finding**:
  - Xinming Chen, Hao Cai, and Tilman Wolf. Multi-Criteria Routing in Networks with Path Choices. In *Proc. of 23rd IEEE International Conference on Network Protocols (ICNP)*, San Francisco, CA, November 2015.
- **Access control**:
  - Hao Cai, Xinming Chen, and Tilman Wolf. OrthCredential: A new network capability design for high-performance access control. In *Proc. of 22nd IEEE International Conference on Network Protocols (ICNP)*, Raleigh, NC, October 2014.
- **Prototype:**
  - Xinming Chen, Tilman Wolf, Jim Griffioen, Onur Ascigil, Rudra Dutta, George Rouskas, Shireesh Bhat, Ilya Baldin, and Ken Calvert. Design of a protocol to enable economic transactions for network services. In *Proc. of IEEE International Conference on Communications (ICC)*, pages 5354–5359, London, UK, June 2015.
- **Economic models**:
  - 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.
  - Luis Marentes, Tilman Wolf, Anna Nagurney, Yezid Donoso, and Harold Castro. Overcoming economic challenges of internet operators in low income regions through a delay tolerant architecture with mechanic backhauls. *NETNOMICS: Economic Research and Electronic Networking*, 15(3):183-213, November 2014.
  - Andres Marentes, Thiago Teixeira, and Tilman Wolf. Exploring economic dynamics in an Internet with service choices. In *Proc. of IEEE International Conference on Communications (ICC)*, London, UK, June 2015.

Thank you!

Tilman Wolf
wolf@umass.edu
http://www.ecs.umass.edu/ece/wolf/