

# Economics of Networking Technology

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# Task List

- Research in the Impact of Pricing Strategies
- The Business Case for Wireless Systems
- The Business Case for Optically Transparent High-speed Networks

# Technology Adoption Among Internet Service Providers

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# Research Questions

- What is the level of technology diffusion among ISPs?
- How do these technologies develop resources that may be used as a competitive advantage?
- How do the relative technology investments (including security) lead to increased firm performance?

# Framework for Analysis

- Adoption leads to survival; increased adoption over time; entrants adopt the technology => resource
- Adoption leads to exit; decreased adoption over time; entrants do not adopt the technology => deadweight resource
- Adoption leads to exit; increased adoption over time; entrants adopt the technology => resource with first mover disadvantage

# Data and Empirical Model

- ISP data in March 2002 and March 2004
  - 2,807 firms in March 2002
  - 1,819 firms in March 2004
    - 1,883 that exited
    - 895 that entered
    - 924 that stayed
- Logistical regression

$$\text{ALIVE} = \beta_0 + \beta_1 \text{CODES} + \beta_2 \text{TRAFFIC} + \beta_3 \text{YEARS} + \sum_{i=1}^n \gamma_i \text{TECH}_i$$

# Technologies

<i>Variable</i>	<i>Technology</i>	<i>Variable</i>	<i>Technology</i>	<i>Variable</i>	<i>Technology</i>
ISDN	"ISDN"	SHELL	"SHELL ACCOUNT"	CONSULT	"CONSULTING"
DSL	"DSL"	SQL	"SQL"	VPN	"VPN"
T1	"T1"	PASSWD	"PASSWORD"	ASP	"ASP"
T3	"T3"	SPAM	"SPAM"	RAUDIO	"REAL AUDIO"
SSL	"SSL"	FILTER	"FILTER"	TOLLFRE	"TOLL FREE PHONE SUPPORT"
WIRELES	"WIRELESS"	COMMER	"COMMERCE"	TFOUR	"24 HOUR SUPPORT"
CABLE	"CABLE"	DBASE	"DATABASE"	MXHOST	"WEB SITE HOSTING" or "WEB HOSTING"
SAT	"SATELLITE"	CGI	"CGI"	MXCOLOC	"COLOCATION" or "CO-LOCATION"
REG	"REGISTRATION"	PGRAM	"PROGRAMMING"	MXSEC	"SECURITY" or "SECURE"
PRIVACY	"PRIVACY"	COLD	"COLD FUSION"	MXWEBDV	"WEB SITE DEVELOPMENT" or "WEB DEVELOPMENT"
FIREWAL	"FIREWALL"	NETWRK	"NETWORK"	MXWEBDS	"WEB SITE DESIGN" or "WEB DESIGN"

# Path Dependency

- Difficult to decrease or shed technologies
  - Once the technology is offered, it is unlikely to remove it as a service offering
  - Pros
    - Learning effects
  - Cons
    - Increased variable costs



# Resources

- Security
  - Increases survivability but entrants only have 3.8% adoption while survivors have 6.4%
- Other technologies
  - DSL, Satellite, Wireless, and Spam all indicate that these are important resources
  - DSL penetration among entrants 53.3% is only slightly higher than entrants, 56.7%

# Deadweight Resources

- Password
  - Reduces survivability and surviving firms have offer fewer password services (0.8%) than the exiting firms (2.3%).
- Legacy systems are avoided by entrants
  - ISDN: 65% => 56%
  - CGI: 5% => 1.9%

# First Mover Disadvantage

- Customer service solutions exhibit a high degree of predicting exit but new entrants and survivors are likely to adopt
  - Toll Free
    - Exiting: 10.6%
    - Survivors: 4.7% => 13.5%
    - Entrants: 59%
  - Twenty Four
    - Exiting: 10.3%
    - Survivors: 4.0% => 10.8%
    - Entrants: 54.7%

# Conclusion

- Security is becoming increasingly important technology for ISPs
- However, security adoption rates are relatively low
- ISPs should avoid adoption of technologies in their nascent stage or ones that have high variable costs

# Network Design

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# WDM Optical Network Design

- WDM takes advantage of the large bandwidth provided by optical networks
- Efficient utilization of these networks requires finding a good solution to logical topology design and traffic routing problems that are very hard to solve optimally when simultaneously optimized!

# Problem Definition

- ❑ The WDM OND problem: A traffic routing problem over a “two-layer” optical network:
  - ❑ Physical topology
    - ❑ Usually considered to be fixed (the number and characteristics of fibers and type of equipment at each node of the network is known in advance)
  - ❑ Logical topology
    - ❑ Design needs to be determined simultaneously with a traffic routing decision.
- ❑ Goal: Given the restrictions on physical and logical topology of WDM network, and the traffic requirements between all pairs of nodes, determine LTD and routing of traffic so that desired objective is minimized/maximized.

# Optimization procedures for the WDM OND problem

- ❑ Large number of heuristic approaches for different network settings. Lack of exact procedures to evaluate the performance of existing algorithms.
- ❑ Exact MIPs for a general case of WDM OND problem are too difficult to solve using commercial optimization software. Even when only a limited number of lightpaths is used, only problems on networks with up to 20 nodes can be solved to optimality
- ❑ An alternative: develop custom, more advanced IP procedure using column generation (CG)



# Summary of current research

- For a special case of WDM OND problem
  - infinite number of wavelengths
  - wavelength changers
  - symmetric demand
  - uniform number of trans/receiversdeveloped a CG algorithm that introduces only a subset of lightpaths
- Preliminary computational results (for 5 randomly generated instances of a 20 node network):
  - Exact mathematical formulation cannot find optimal solution within 10 hrs of cpu time
  - Our CG procedure provided similar solution quality within less than one hour. Compared to results of exact mathematical formulation on average our CG provided 0.08% worse UB and 0.55% worse LB

# Future work

- ❑ Develop exact IP CG algorithms for:
  - ❑ Special case of WDM OND problem studied so far and
  - ❑ More general optical network setting
- ❑ Develop efficient heuristics for initialization of the IP CG algorithm
  
- ❑ Preliminary write-up and results available in “A Column Generation Procedure for the WDM Optical Network Design Problem” by D. Stanojevic

# Wireless Network Design Research

- Spectrum Auctions – Day and Raghavan
  - Survey paper in preparation
  - CAMBO, a bidding language for combinatorial auctions
- Multi-period traffic routing in satellite networks
  - Problem occurs in network of geostationary satellites
  - Given configuration of network traffic demand that changes by period, network configuration that changes by period, develop a minimum cost routing plan. (Problem is extremely difficult to solve exactly).
  - Developed a (multi-period) path-based multi-commodity integer programming formulation and a branch-and-price-and-cut solution procedure.
  - Preliminary computational results encouraging.

# Publications

- “CAMBO: Combinatorial Auctions using Matrix Bids with Order,” R. Day and S. Raghavan, submitted for publication, *Operations Research*.
- “The Multi-Level Capacitated Minimum Spanning Tree Problem,” I. Gamvros, B. Golden, and S. Raghavan, Submitted, *INFORMS Journal on Computing*.
- “Low-Connectivity Network Design on Series-Parallel Graphs,” S. Raghavan, *Networks* **43**(3), pp 163-176, 2004.
- “Long Distance Access Network Design” R. Berger and S. Raghavan, *Management Science* , **50**(3), pp 574-592, 2004.
- “Heuristic Search for the Generalized Minimum Spanning Tree Problem,” B. Golden, S. Raghavan, and D. Stanojevic, Accepted, *INFORMS Journal on Computing*.

# Publications

- “Heuristic Search for Network Design,” B. Golden, I. Gamvros, S. Raghavan, and D. Stanojevic. To appear in *Operations Research and Technology: Tutorials from INFORMS 2004*, edited by Harvey Greenberg (Kluwer Academic Press) 2004.
- “Ex-Post Internet Charging: An Effective Bandwidth Model,” J. Bailey, I. Gamvros, and S. Raghavan, under revision for *ACM Transactions on Internet Technology*.
- “Technology, Infrastructure, and Resources: An Empirical Analysis of Internet Service Providers,” J. Bailey and T. Porterfield, to be submitted to *Management Science*.

# Presentations

- “Directed Connectivity Splitting for Survivable Network Design” presented CORS/INFORMS Joint International Meeting May 16-19 2004, Banff, Alberta, Canada
- “Long Distance Access Network Design” --- March 5, 2004, UMBC Mathematics Department, July 2, 2004, IBM Research.
- 7th INFORMS Telecommunications Conference, March 7-10 2004, Boca Raton, Florida
  - A Note on Search by Objective Relaxation
  - The Prize-Collecting Generalized Minimum Spanning Tree Problem
- INFORMS Annual Meeting October 19-22, 2003 - Atlanta
  - A Note on Eswaran and Tarjan's Strong Connectivity Augmentation Algorithm
  - Combinatorial Auctions using Matrix Bids
  - Heuristic Search for the Generalized Minimum Spanning Tree Problem
  - Improved Heuristics for the Multi-level Capacitated Minimum Spanning Tree Problem
- “CAMBO: Combinatorial Auction using Matrix Bids with Order” presented at the 18<sup>th</sup> International Symposium on Mathematical Programming, August 18-22 2003, Copenhagen, Denmark.

# Doctoral Students Supported

- Robert W. Day (Applied Mathematics)
- Ioannis Gamvros (Business)
- Tobin Porterfield (Business)
- Daliborka Stanojevic (Business)