Free-Riding and Whitewashing in Peer-to-Peer Systems

3rd Annual Workshop on Economics and Information Security
May 2004

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Motivation
Peer-to-Peer Systems

- P2P systems rely on voluntary contribution of individuals
- Rational users may act to maximize their own utility
  - Empirical evidence for selfish behavior [Adar (2000), Saroiu (2002)]
- Individual rationality may conflict with overall system objective
- Realigning the incentives of individual users with the system's overall performance is crucial

Motivation
Free Identities

- Many incentive schemes are based on reward to contributors and/or penalties to free-riders
- How can we identify free-riders?
  - Reputation systems
- whitewashing attack
  - Made feasible by “cheap pseudonyms” [Friedman and Resnick (1998)]

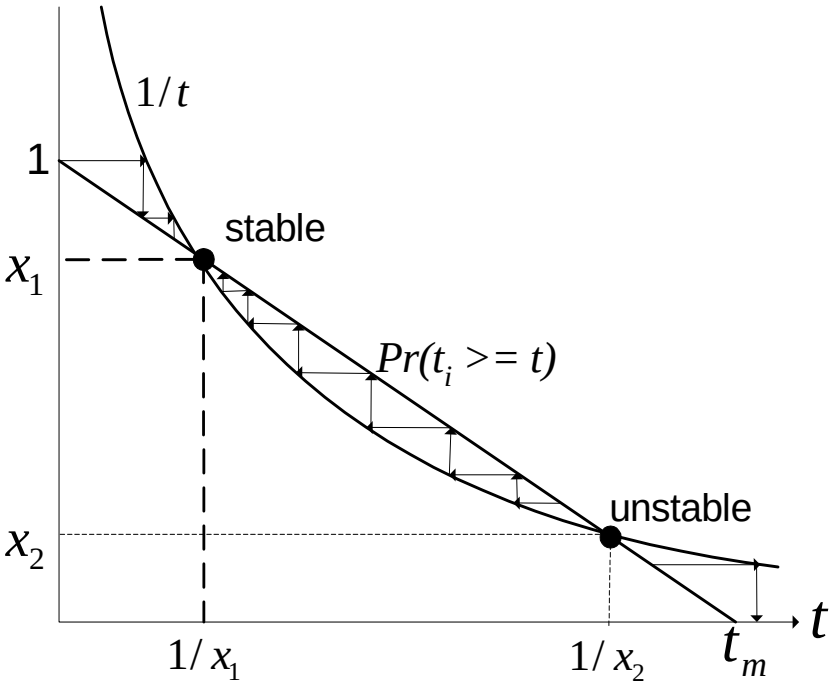
Research Objectives

- Devise an analytic model to explore how the level of free-riding and system performance in P2P systems are influenced by:
  - Societal generosity
  - System utility
  - Incentive mechanism
- Quantify the loss in system performance due to free identities

Model

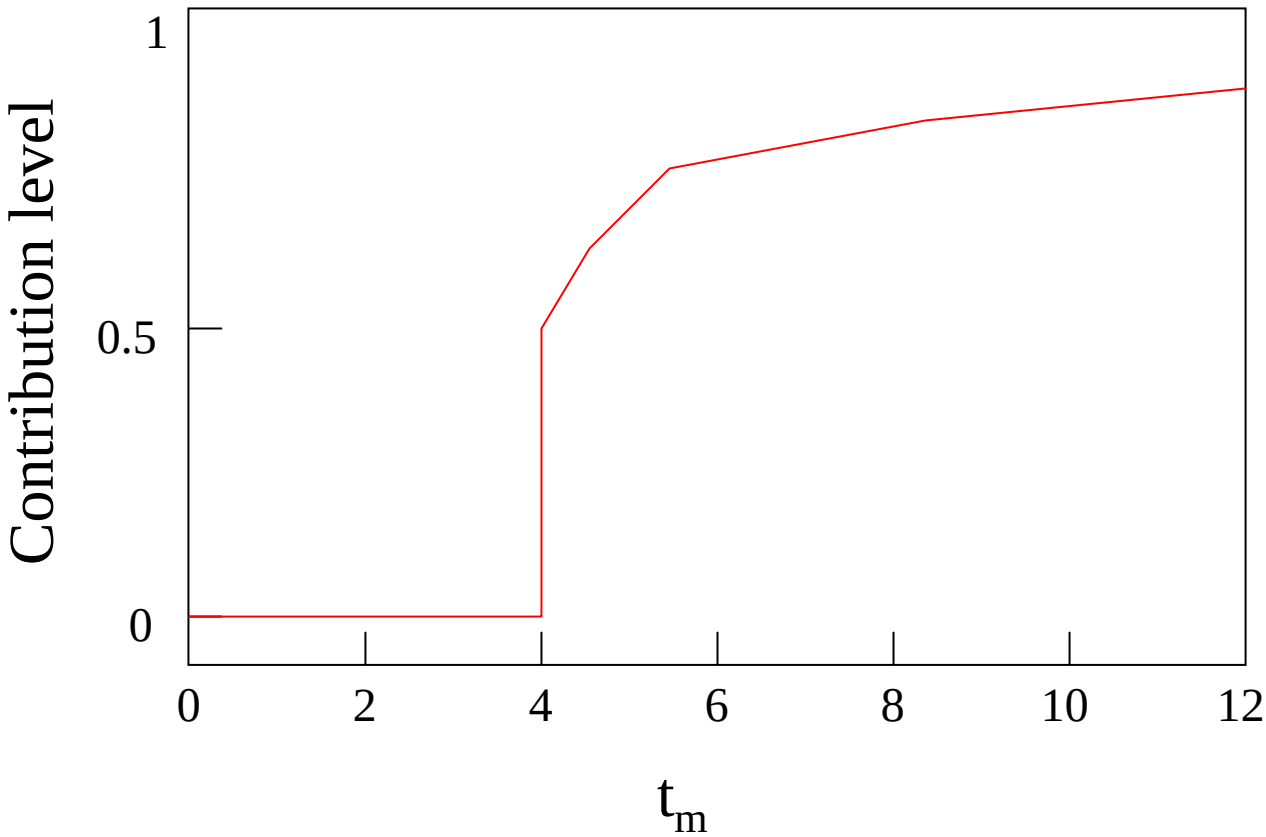
- Rational agent with type t_i (generosity level)
- Individual agents decide whether to contribute or free-ride
- Individual cost of contribution, $R_i = 1/x$
  - Where x is the fraction of users who contribute
- Rational decision:
  - if $t_i > 1/x$: Contribute
  - Otherwise: Free-ride
- Contribution level in equilibrium: $x = \Pr(t_i \geq \frac{1}{x})$

Contribution Level in Free-Market



- $t_i \sim U(0, t_m)$
- t_m reflects the societal generosity
- $x = \Pr(t_i \geq \frac{1}{x}) = 1 - \frac{1}{x t_m}$
- $x_{1,2} = \frac{t_m \pm \sqrt{t_m^{\,2} - 4t_m}}{2t_m}$
- System sustained for $t_m > 4$

Cooperation Level as a Function of Societal Generosity



System Benefits and Performance

- User's individual benefit: $Q_i = \alpha x^{\beta}$
  - $\alpha > 0$ (benefit coefficient)
  - $\beta <= 1$ (diminishing returns coefficient)

- System performance:

$$W = \underbrace{\Sigma Q_i}_{\text{all users}} - \underbrace{\Sigma R_i}_{\text{contributors}} = \alpha x^{\beta} - 1$$

Total benefit

Total cost

Incentive Mechanisms

- How effective are incentive mechanisms in encouraging cooperation and improving performance?
  - Penalty
  - Exclusion
  - Entry fee
  - Etc.

Penalty Mechanism

Q	Benefit
R	Burden (contribution cost)
T	Threat

- Free-riding behavior entails a penalty p
  - Service differentiation
  - Catch and exclude with probability p
- Penalty increases cooperation level by:
  - Reducing burden (R) to contributors
  - Introducing threat (T) to free-riders
- Realized performance:

$$W_{contributors} = Q - R$$

$$W_{free-riders} = Q - T$$

- Contribution level: $x = \Pr(t_i \geq R - T)$

$$\frac{x + (1-x)(1-p)}{x}$$

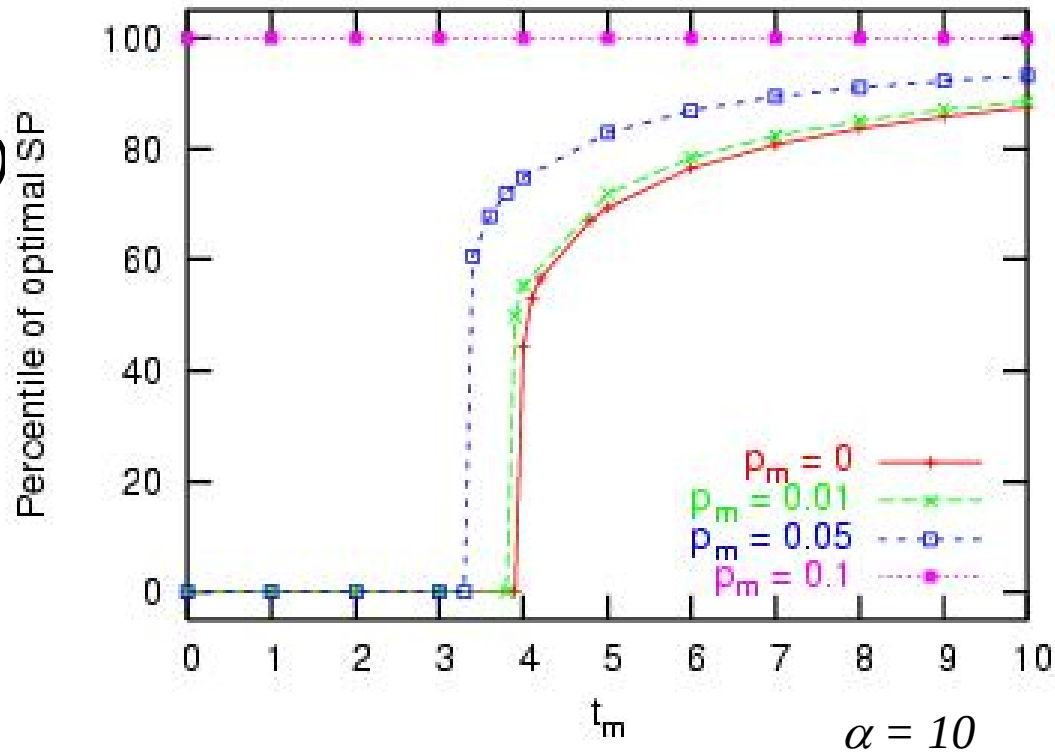
$$p \propto x^{\beta}$$

System Performance under the Penalty Mechanism

- System performance:

  $W = (\alpha x^{\beta} - 1)(x+(1-x)(1-p))$

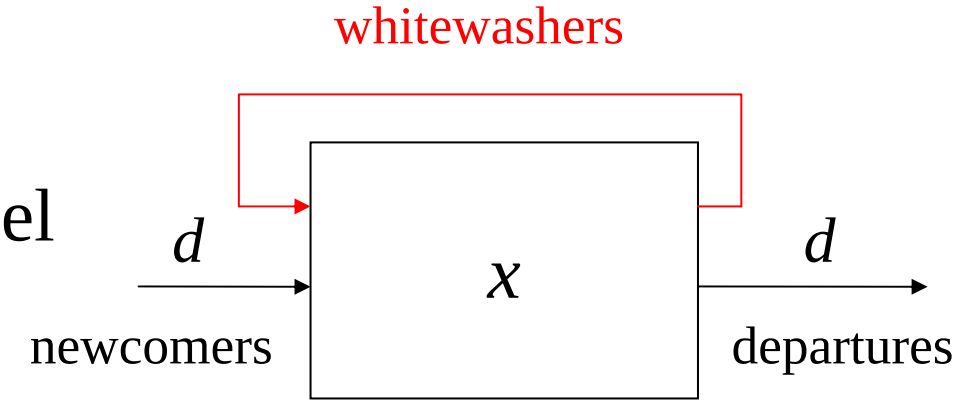
- Effect of penalty:
  - Social gain: higher x
  - Social loss: reduced benefit to free-riders
- $p^* = arg\ max_p\ W$
- If $p > 1/\alpha$, then $x=1$
- The required p to achieve optimal performance decreases in α



Whitewashing Attack

- With the availability of free-identities, free-riders can engage in whitewashing:
  - Repeatedly leave system and rejoin with new identity
  - Avoid penalty imposed on known free-riders
- What is the social cost of free-identities?

Whitewashing



- Extend to dynamic model with turnover
  - Arrivals, departures, and whitewashers
- Permanent identities vs. Free identities
- How effective is penalty mechanism in the presence of whitewashing?
  - Impossible to penalize only known free-riders
  - Penalize all newcomers (including whitewashers and legitimate newcomers)?

Population Mixture

Permanent identities

- Existing contributors (EC)
- X **Existing free-riders (EF)**
- New contributors (NC)
- New free-riders (NF)

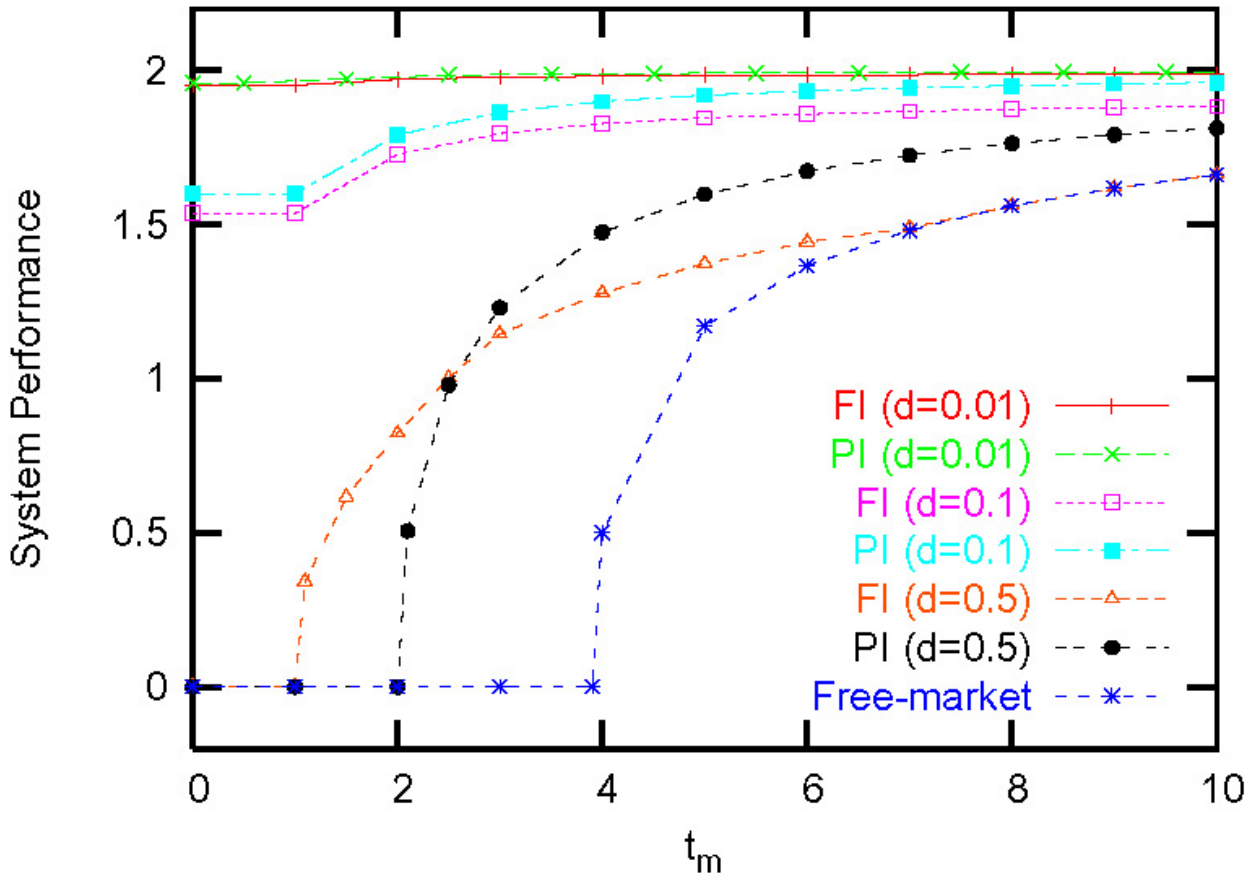
Free identities

- Existing contributors (EC)
- X **Whitewashers (WW)**
- X New contributors (NC)
- X New free-riders (NF)

	Permanent	Free
Penalized	(1-d)(1-x)	(1-d)(1-x)+d
Not penalized	(1-d)x+d	(1-d)x

System performance in each scenario is the sum of the realized performance levels of all the groups

System Performance



Significant social loss due to free identities incurred only for high turnover rates

Conclusions

- Study the phenomenon of free-riding and the effect of free identities in P2P systems
- Quantify the effectiveness of penalty mechanisms on encouraging cooperation and discouraging whitewashing behavior
- Possible future directions include: additional incentive mechanisms, alternate system dynamics, resource heterogeneity and finite identity costs

Questions?

- For more information, visit: http://p2pecon.berkeley.edu/