# An Incentive Mechanism for Message Relaying in Peer-to-Peer Discovery

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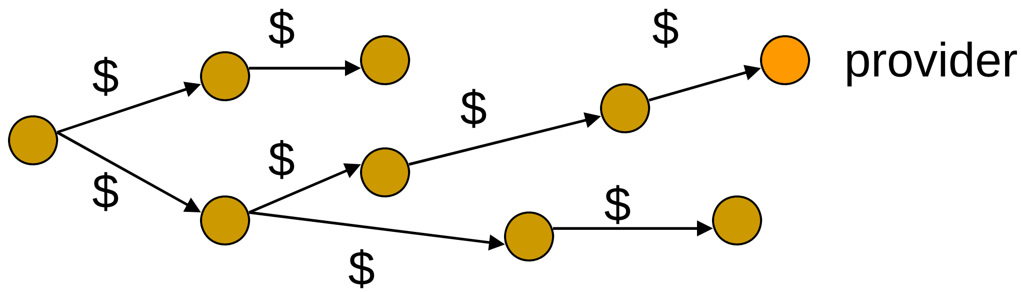
# Peer-to-Peer Discovery

- Peer discovery is important in a P2P system for peers to exploit distributed resources
- Message relaying for peer discovery in a distributive model ("word-of-mouth")
- Common searching protocols:
  - breadth-first search (Gnutella)
  - depth-first search (Freenet)

# Problems

- Efficiency
  - BFS costs enormously the bandwidth although the results can be found quickly
  - DFS is cheaper in communications but the response time can be very long
- Incentive
  - Each peer may represent a self-interested entity
  - Communication bandwidth and energy are bounded resources
  - A peer may drop searching messages from other peers to save resources (*free riding*)
  - A *different* problem from the message relaying mechanism in distributed *routing*

# The Incentive Mechanism




- An incentive mechanism overcomes the flooding problem of BFS while reserving the quick response feature
- It is motivated by the following requirements:
  - Communication efficiency
  - Reliability
  - Anonymity and information locality

# Communication Efficiency

- *Overlapping*: the wasted transmissions of the message to the peers that have received the message
- The system becomes *saturated* quickly if each peer makes significant transmission efforts
- To reduce the inefficiency caused by overlapping, a peer should adjust the effort with the saturation status.

# Reliability

- The probability of finding a provider is positively correlated with the transmission efforts.
- Reliability is a conflicting goal with reducing the communication cost.
- Trade off the communication cost and reliability to maximize the utility.
- The optimum depends on the value of information.

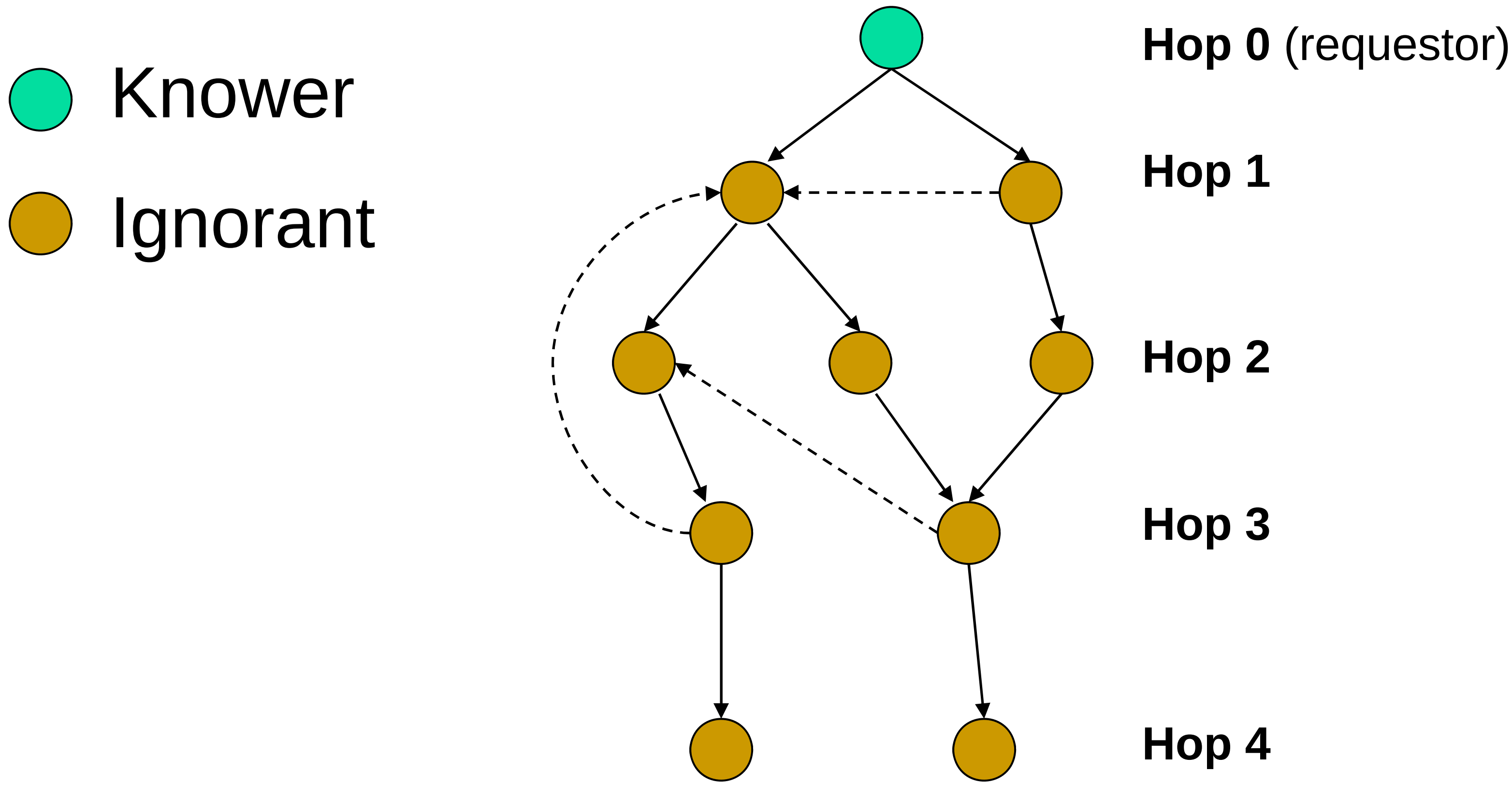
# Anonymity and Information Locality

- A micro-payment system that prices the scarce resource is commonly used to provide incentive compatibility.
- The usual micro-payment mechanism is NOT feasible in P2P discovery system:
  - With *anonymity* the intermediate peers on the route and their transmission efforts are not identifiable by the source node.
  - Pricing is difficult as the *local* environments are unknown to the mechanism designer or a third party ("non-private value revelation" in Shneidman & Parkes).
- Price the searching result that only require local information that is easy to obtain/verify by local price makers, e.g., neighbors, immediate upstream nodes, and incentives received and passed.

# Agenda

- The relaying model
- Equilibrium analysis
- Experiments
- Conclusion

# The Relaying Model



# The Relaying Model (cont.)

- Assumptions
  - Single provider
  - Homogeneity
- Parameters
  - Message relaying cost: $c(k)$, increasing and convex
  - Number of peers: $N$
  - Max hop number ($TTL$): $H$, i.e., $H+1$ hops allowed
  - Information value: $v_0$

# Equilibrium Analysis

- Individual strategy:

$$(k_i,u_i)=S_i(h_i,v_i)$$

- Individual utility:

$$U_i(S)=(v_i\text{-}u_i)L_i(S)/N\text{-}c(k_i)$$

- System utility:

$$U(S)=v_0L_0(S)/N\text{-}\sum c(k_i)$$

- Sub-game perfect Nash Equilibrium (SPNE): a Nash equilibrium for each subgame of the propagation process starting from each hop to the last hop.

# Equilibrium Analysis (cont.)

PROPOSITION 2.1. [4] *Given the incentive relaying strategy $u_i(h_i, v_i)$ for each peer $i$, a SPNE of the transmission strategies $\{k_i^*(h_i, v_i|u_i)\}_{i \in N}$ exists. $k_i^*(h_i, v_i|u_i)$ decreases with the increase of $h_i$ or $u_i$, or with the decrease of $v_i$.*

PROPOSITION 2.2. *With a best response strategy the increase of the input incentive leads to the increase of the expected number of downstream nodes.*

PROPOSITION 2.3. *If all peers have the same degree, a symmetric SPNE exists and is unique.*

# Approximation of Symmetric SPNE

- The expected ignorants reached by each peer in hop $h$ is

$$\hat{k}_h = \begin{cases} 0 & \text{if } k_h = 0 \text{ or } m_h = 0 \\ \frac{N-n_h}{m_h}[1-(1-\frac{k_h}{N-1})^{m_h}] & \text{else.} \end{cases}$$

- Estimate the number of peers in hop h+1:

$$m_{h+1} \doteq m_h \hat{k}_h = (N - n_{h-1} - m_h)[1-(1-\frac{k_h}{N-1})^{m_h}]$$

- Estimate the number of descendants of a peer in hop h:

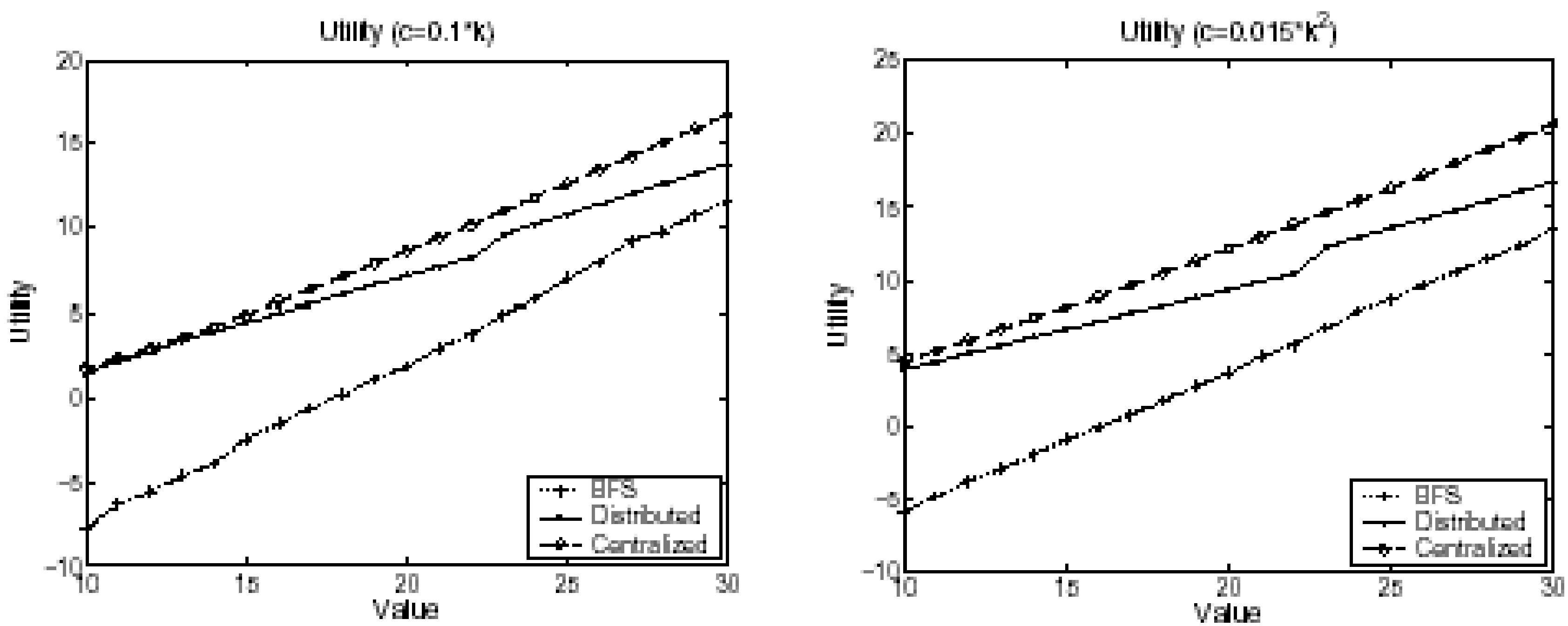
$$L_h(n_h, m_h) = \sum_{l=h+1}^{H} m_l / m_h$$

- An approximate SPNE can be calculated by backward induction.

# Experiments

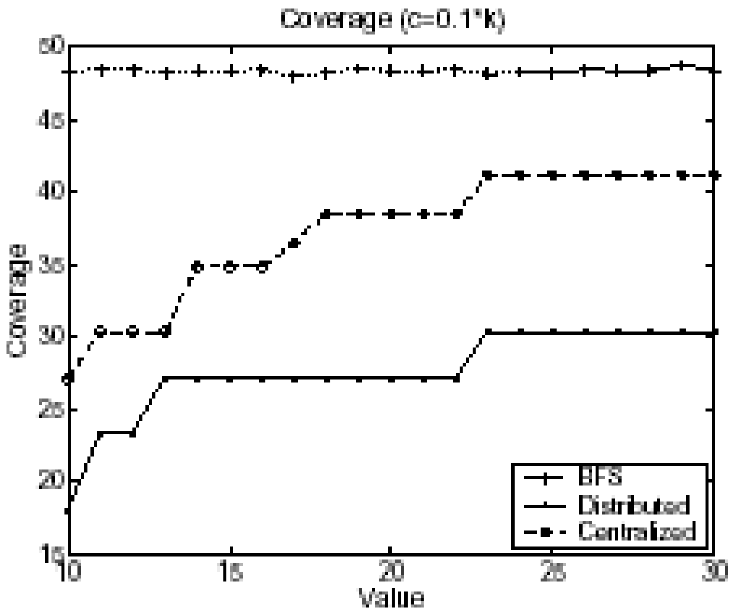
- Three systems:
  - The distributed incentive mechanism (based on the approximate SPNE strategy)
  - The breadth-first search mechanism
  - The centralized mechanism (maximizes the system utility based on the approximate coverage function)
- We are interested in:
  - The system total utility (efficiency)
  - The coverage (reliability)
  - The distribution of transmission effort and incentives over hops in the distributed incentive mechanism
- $N$=50, $H$=2 (three hops), $D$=6, $v_0$=10 to 30, $c(k)=0.1k$ or $0.015k^2$

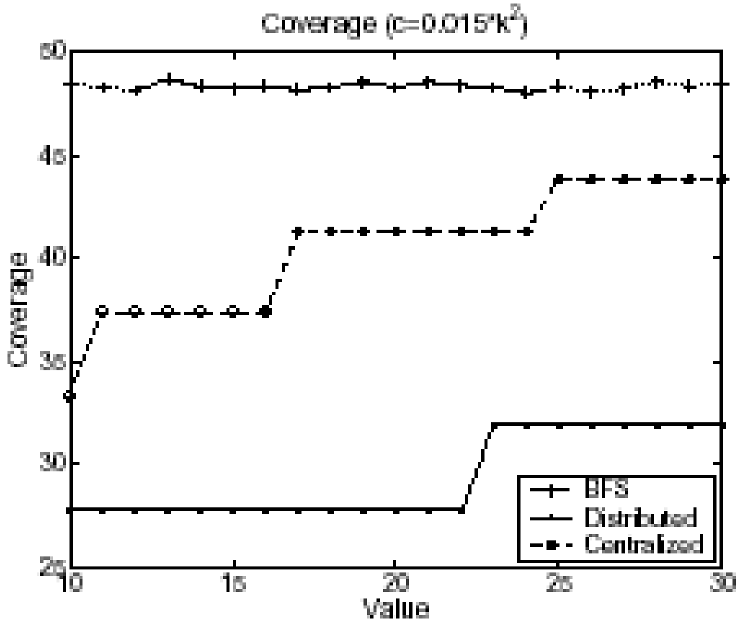
# System Utility




- $U_{BFS} < U_{dist} < U_{cen}$ with $U_{dist}$ generally higher than 80% of $U_{cen}$
- $U_{dist}$ - $U_{BFS}$ decreases with the increase of information value.

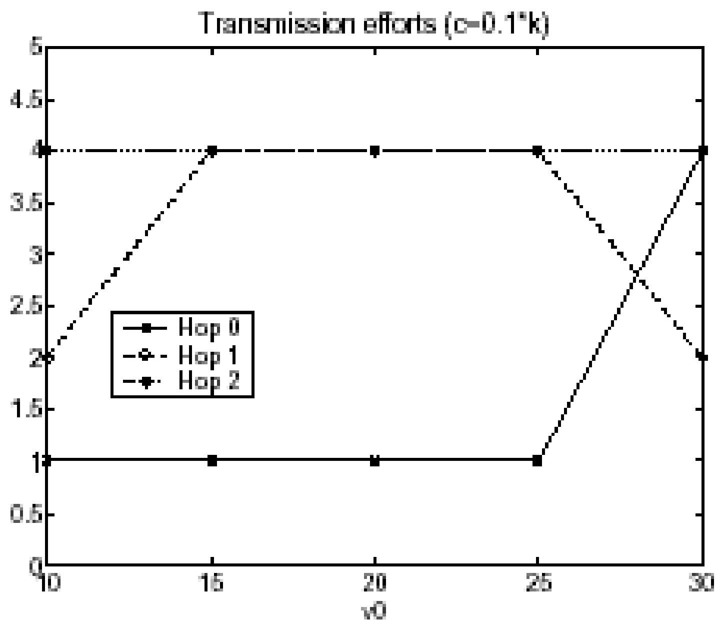
# Coverage

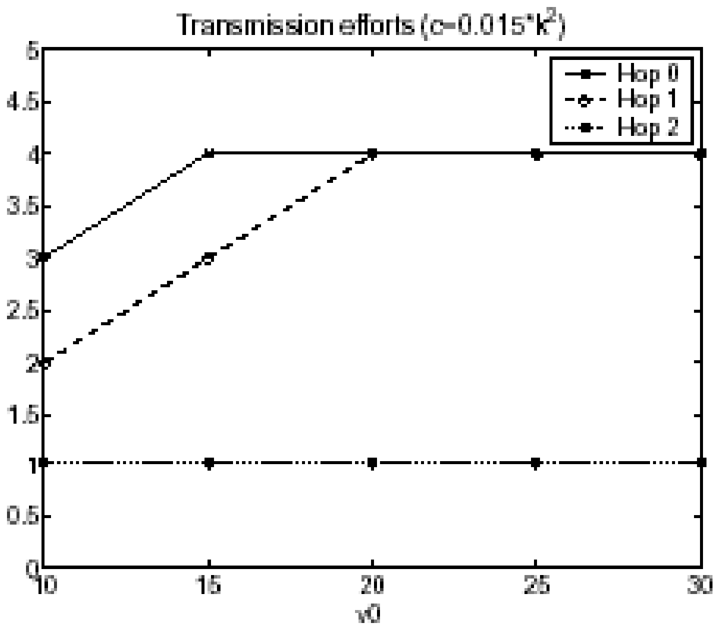



- BFS has the highest coverage, which does not depend on the information value.
- The coverage of both the distributed and centralized system increases with the information value
- The distributed mechanism cannot achieve the optimal coordination.

# Distribution of Transmission Efforts and Incentives




With a more convex cost function, a peer tends to develop its family tree by its own transmission efforts, and pass little incentives to downstream nodes.

# Conclusion

- An incentive mechanism for message relaying in P2P discovery that prices the searching *results* instead of the searching *behavior*.
- Optimal TTL?
- Multiple providers?
- Peers are heterogeneous and have knowledge?