A Peer-to-Peer Approach to Sharing Wireless Local Area Networks

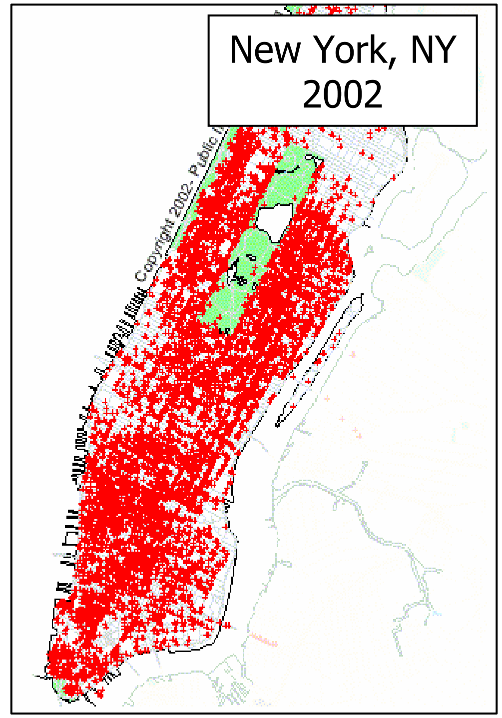
PhD Dissertation

Elias C. Efstathiou

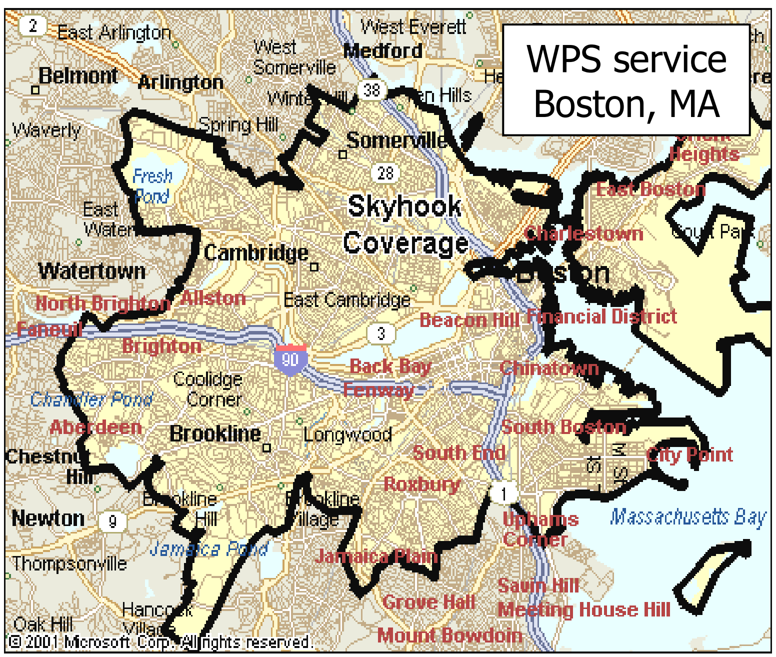
Advisor: Professor George C. Polyzos

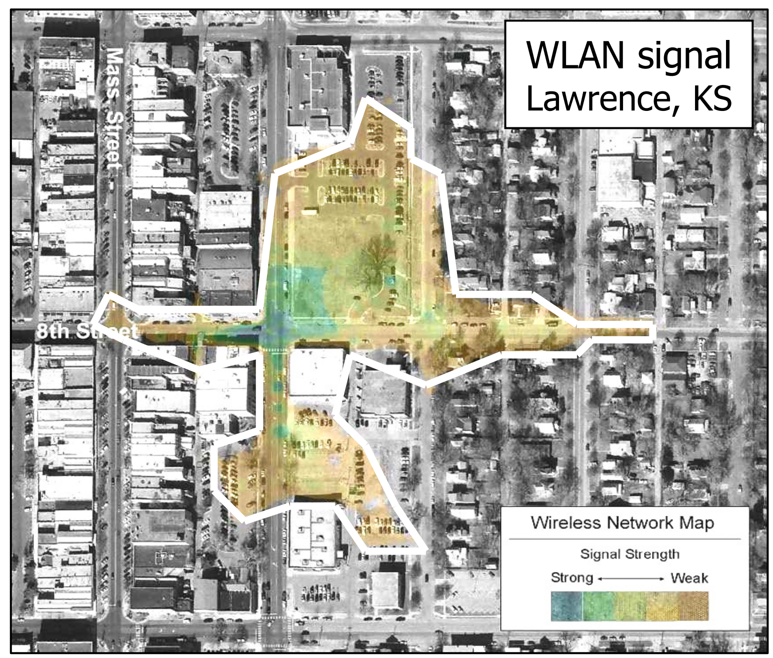
Athens University of Economics and Business
Department of Computer Science

Motivation



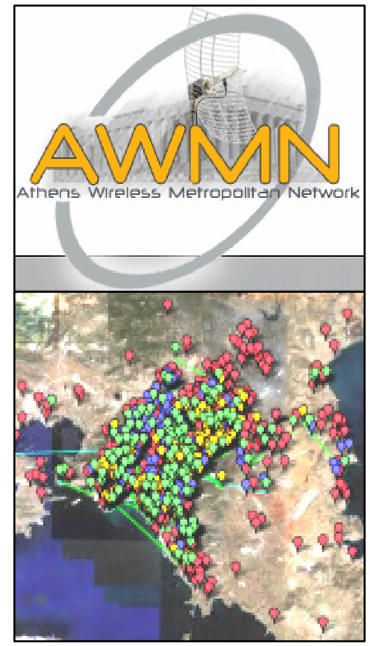
- Numerous WLANs in metropolitan areas
- Signal covers greater area than intended
- The case of Skyhook Wireless, Inc.
  - Wi-Fi Positioning System: a GPS-like service
  - Relies on database of WLAN beacon signals





WLAN Technology

- Access bandwidth: 11-54 Mbps (IEEE 802.11b, g)
- Backhaul bandwidth
  - Internet connections: DSL now up to 8 Mbps in London
  - Wireless Community Networks: 54 Mbps backbone in AWMN
- WLAN-enabled phones available



- WLANs: An alternative to cellular?
  - Faster
  - Maximum RF power: 100–200 mW vs. 1–2 W
  - Handovers not a problem for low-mobility video, audio, browsing

Observation

- WLANs and their backhaul have excess capacity
- Technically, we *could* share them, however:
  - Direct and indirect costs in sharing
  - If WLAN owners rational → no one shares

The Peer-to-Peer Approach:

Payments 'in kind'

  - Rely on subscriptions, pay-as-you-go schemes
  - Revenue sharing with WLAN owner
    - Focus on public venues (Boingo, iPass)
    - Focus on residential WLANs (Netshare, FON)

Peer-to-Peer Incentives: Literature

i. Tie consumption to contribution, relying on:
   - Central bank, which issues community currency [1]
   - Distributed bank, which keeps track of accounts [2]
   - Tamperproof modules, which enforce reciprocity [3]
   - Simple Tit-For-Tat [4]

ii. Fixed contribution scheme, properties shown in [5]

[1] B. Yang and H. Garcia-Molina, PPay: micropayments for peer-to-peer systems, 10th ACM Conference on Computer and Communications Security (CCS'03), Washington, DC, 2003.

[2] V. Vishnumurthy, S. Chandrakumar, and E. G. Sirer, KARMA: a secure economics framework for P2P resource sharing, 1st Workshop on Economics of Peer-to-Peer Systems (p2pecon'03), Berkeley, CA, 2003.

[3] L. Buttyán and J.-P. Hubaux, Stimulating cooperation in self-organizing mobile ad hoc networks, *ACM/Kluwer Mobile Networks and Applications*, vol. 8, no. 5, 2003.

[4] R. Axelrod and W. D. Hamilton, The evolution of cooperation, *Science*, vol. 211, 1981.

[5] C. Courcoubetis and R. Weber, Incentives for large peer-to-peer systems, *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 5, 2006.

Peer-to-Peer Incentives: Requirements

1. Central bank
   – Requires a central authority
2. Distributed bank
   – Requires altruists: to form overlay network, to hold accounts
3. Tamperproof modules
   – Requires trusted hardware/software
4. Tit-For-Tat
   – Requires permanent IDs, repeat interactions

Whitewashing [6] and Sybil attacks [7]: problem for all schemes

[6] M. Feldman, C. Papadimitriou, J. Chuang, and I. Stoica, Free-riding and whitewashing in peer-to-peer systems, *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 5, 2006.

[7] J. Douceur, The Sybil attack, 1st International Workshop on Peer-to-Peer Systems (IPTPS'02), Cambridge, MA, 2002.

Our Requirements

The Peer-to-Peer Wireless Network Confederation scheme:

1. Must assume rational peers—at all layers
2. Must be implementable on common WLAN APs
3. Must not rely on authorities, therefore:
   - Must not rely on central servers, super-peers
   - Must not rely on tamperproof modules
   - Must assume IDs are free and that anyone can join, and must penalize newcomers—proven unavoidable in [8], [9]

[8] E. Friedman and P. Resnick, The social cost of cheap pseudonyms, *Journal of Economics and Management Strategy*, vol. 10, no. 2, 1998.

[9] M. Feldman and J. Chuang, The evolution of cooperation under cheap pseudonyms, 7th IEEE Conference on E-Commerce Technology (CEC), Munich, Germany, 2005.

P2PWNC Architecture and Algorithms

System Model

- P2PWNC Team/Peer
  - Team ID: public-private key pair
  - Team founder and team members
  - Member IDs and member certificates
    - No PKI required

Member certificate

Team public key
Member public key
Team signature

- Team/Peer components
  - P2PWNC clients, storing:
    - Member certificate
    - Member private key
  - P2PWNC APs, storing:
    - Team public key
  - Team server, storing:
    - Team receipt repository

P2PWNC Receipts

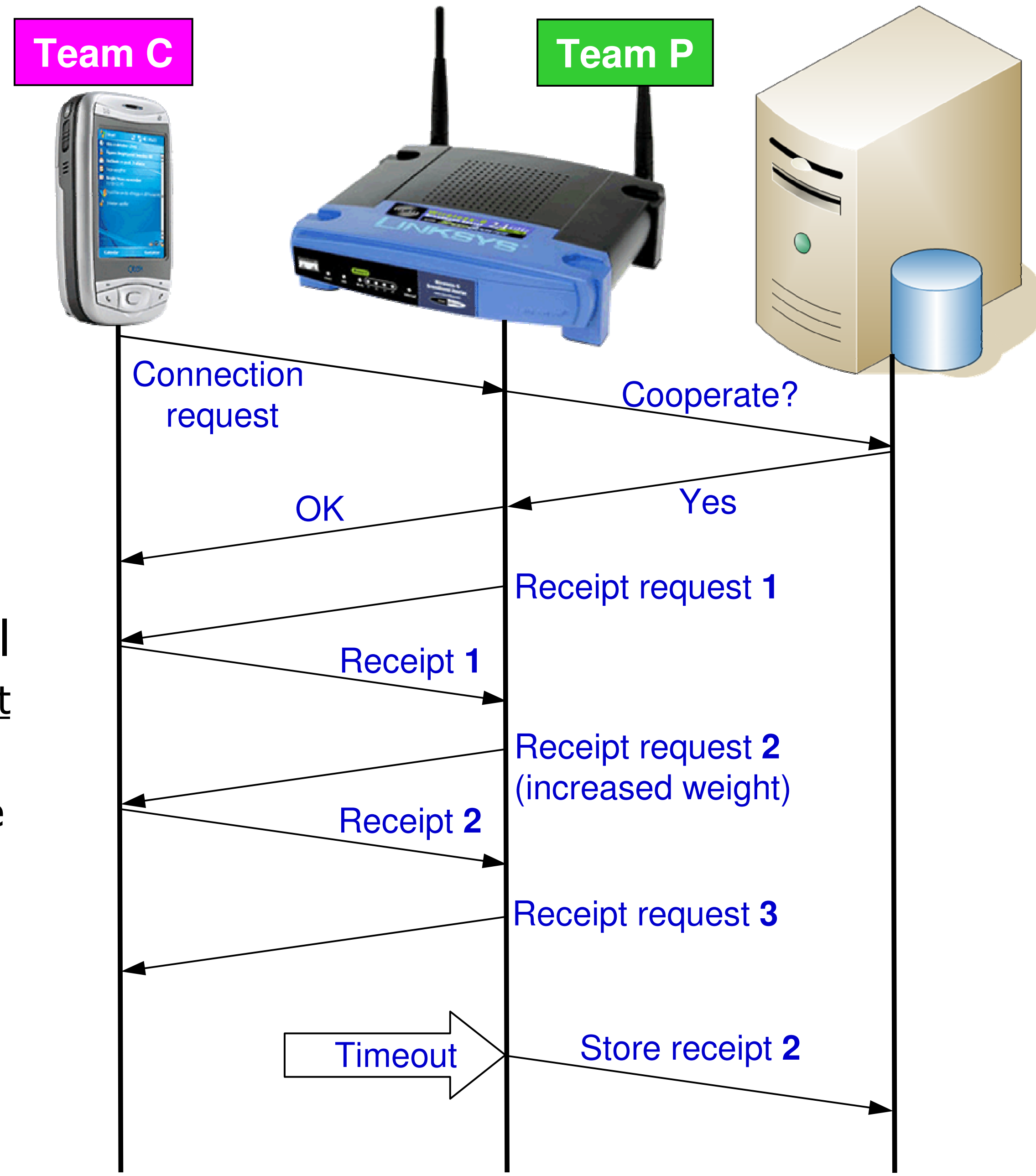
P2PWNC receipts
- Proof of prior contribution

Provider public key
Consumer certificate
Timestamp
Weight (bytes)
Consumer signature

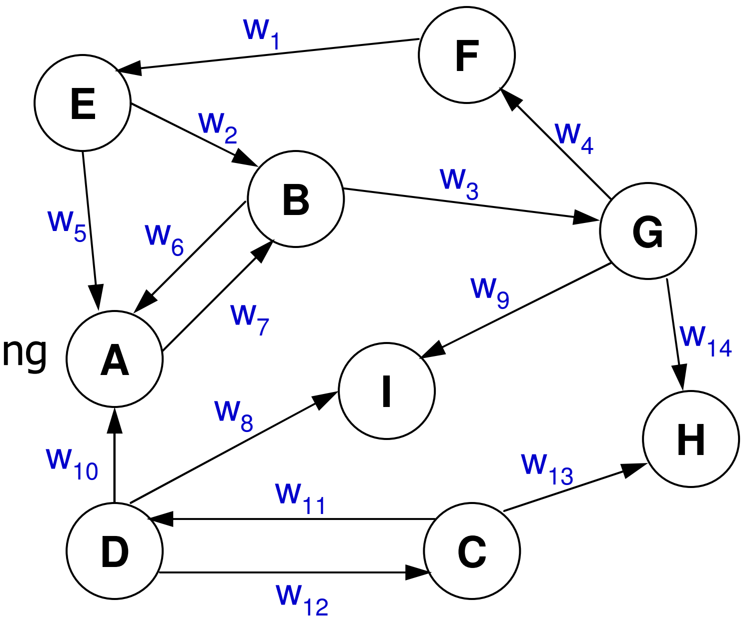
Receipt generation protocol

<u>The only time two teams interact</u>

1. Consumer presents certificate
2. Provider decides
3. Provider periodically requests receipt
4. Consumer departs



The Receipt Graph



A logical graph

- Vertices represent team/peer IDs
- Edges represent receipts
- Edges point **from** consumer **to** contributor (they represent 'debt')
- Edge weight equals sum of weights of corresponding receipts

Possible manipulations

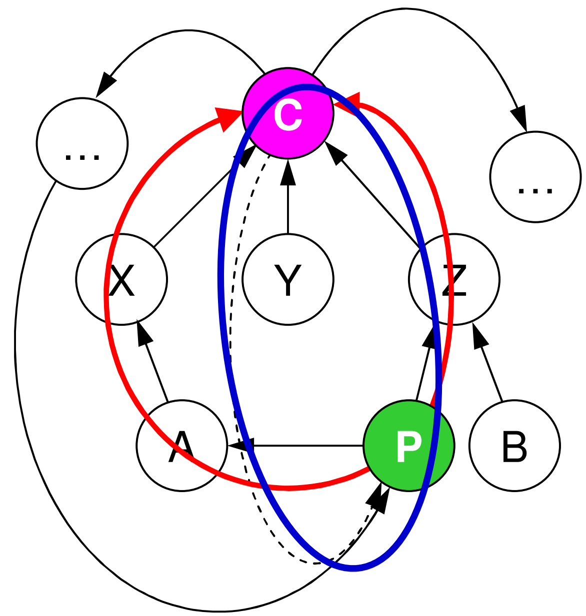
- A peer **can** create many vertices
- A peer **can** create many edges starting from these vertices
- A peer **cannot** create edges starting from vertices he did not create
- A peer **cannot** change the weights on edges

For the analysis that follows, assume that a central server exists, which stores the entire receipt graph

Maxflow-based Decision Rule

- What if a prospective consumer **C** appears at the root of a tree of receipts?
  - All IDs and receipts could be fake!
- What if the prospective contributor **P** sees himself in the tree?
  - **P** owes direct or indirect debt to **C**
  - Potential for multi-way exchange, like in [10]
- Find all direct and indirect debt paths [11]
  - Maxflow from **P** to **C**
- Find also direct and indirect debt paths from **C** to **P**
  - Ref. [11] proposes that **P** cooperates with probability:

$$p = \min\left(\frac{mf\,(P \to C)}{mf\,(C \to P)},\ \ 1 \right)$$



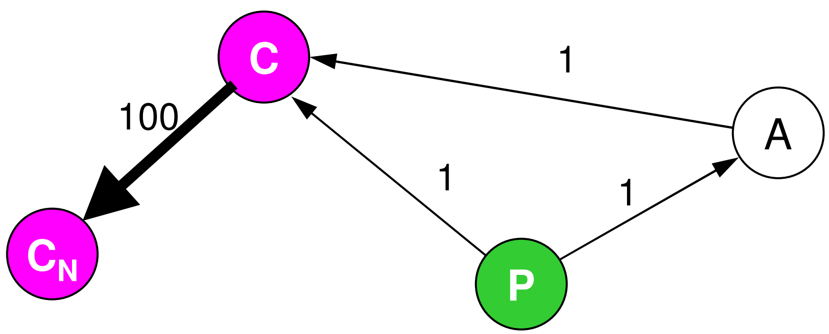
[10] K. G. Anagnostakis and M. B. Greenwald, Exchange-based incentive mechanisms for peer-to-peer file sharing, 24th International Conference on Distributed Computing Systems (ICDCS 2004), Tokyo, Japan, 2004.

[11] M. Feldman, K. Lai, I. Stoica, and J. Chuang, Robust incentive techniques for peer-to-peer networks, ACM Conference on Electronic Commerce (EC'04), New York, NY, 2004.

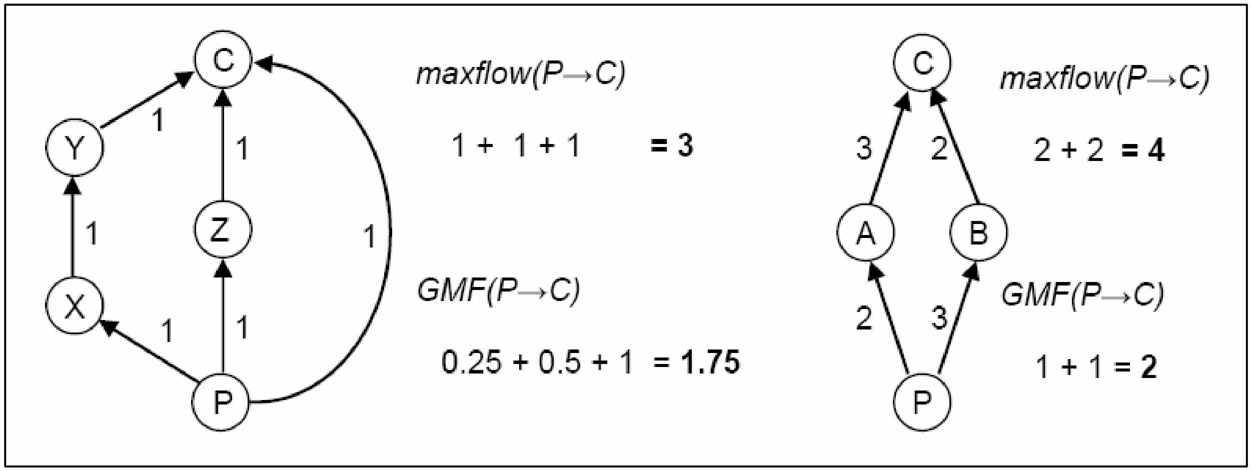
Two Problems with Maxflow-based Decision

$$p = \min\left(\frac{mf(P \to C)}{mf(C \to P)},\ 1 \right)$$

1. Cooperate with a probability?
   - Encourages continuous re-requests
   - Answer: Interpret fraction as service differentiation
2. Problem in denominator
   - Attacker can always get best service with small maxflow in the numerator as long as he 'erases debt' using new ID
   - Answer: GMF heuristic



P2PWNC Reciprocity Algorithm



$$r_1 = \min\left(\frac{mf(P \rightarrow C)}{mf(C \rightarrow P)},\ 1\right)$$

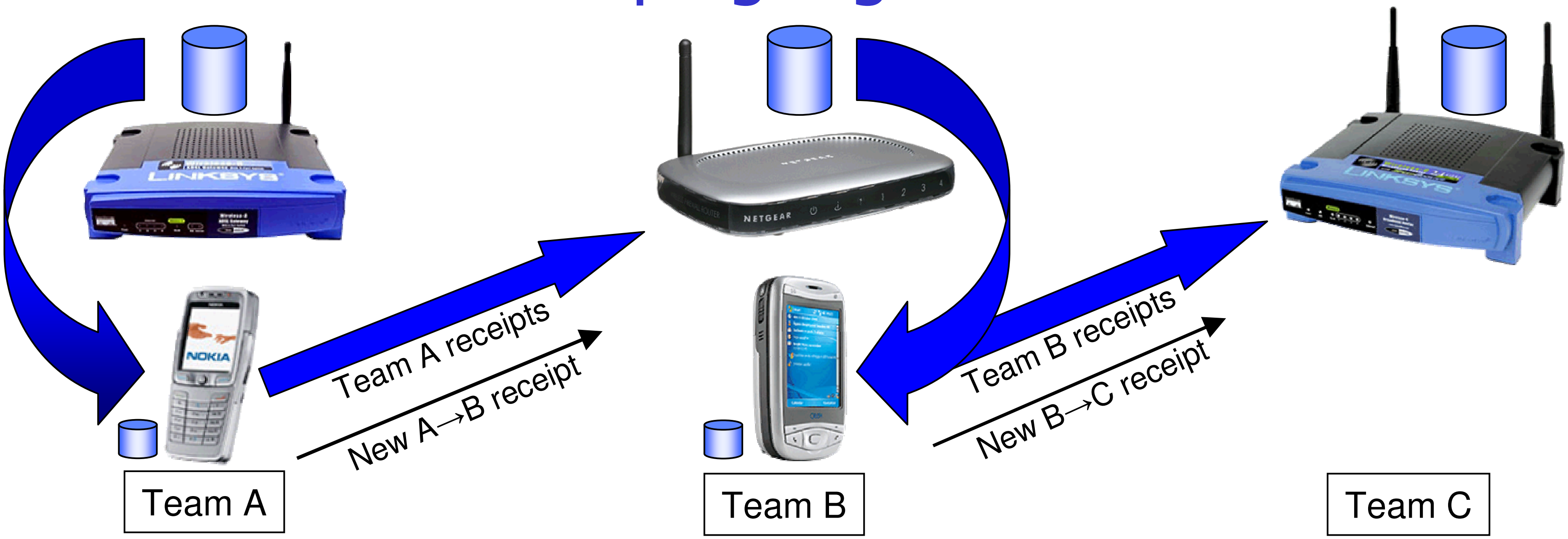
$$r_2 = \frac{GMF(P \rightarrow C)}{gmf_{avg}}$$

$$gmf_{avg} \leftarrow gmf_{avg}\ a\ +\ GMF_{new}\ (1 - a)$$

$$SRM_{P \rightarrow C} = \min(1,\ r_1\, r_2)$$

- First, work around ‘erase debt’ attack with Generalized Maxflow (GMF)
  - GMF heuristic: examines directness of debt
  - Punishes those who ‘push’ good reputation away
- Subjective Reputation Metric (SRM)
  - P2PWNC APs use this to guide cooperation decisions

Gossiping Algorithm



- Realize the receipt graph without overlays or central servers (idea based on [12])
  - Server receipt repositories
  - Client receipt repositories
- Phase 1: Client update
  - Get fresh receipts from team
- Phase 2: Merge
  - Show these receipts to prospective contributors
  - Contributor merges these receipts with 'oldest-out' replacement

[12] S. Čapkun, L. Buttyán, and J.-P. Hubaux, Self-organized public key management for mobile ad hoc networks, *IEEE Transactions on Mobile Computing*, vol. 2, no. 1, 2003.

Notes on Gossiping Algorithm

- Teams do not show outgoing receipts to other teams
- Members do not show own consumption to their team
  - Gossiping will be enough to find (some of) them
- Short-term history due to finite repositories encourages continuous contribution

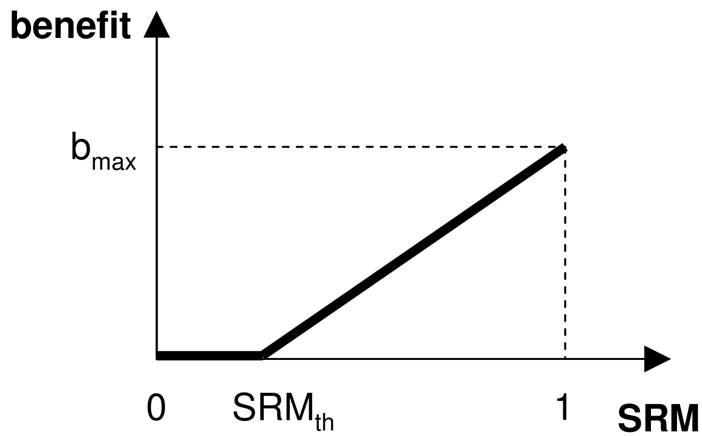
Bootstrap Algorithm

- New teams/peers must contribute to the system first
  - Maxflows **from** and **to** a new ID are zero
    - New peer appears as free-rider to others
    - Others appear as free-riders to new peer
  - Cooperate with everyone at first
    - Including free-riders…
- For how long?
  - The 'patience' heuristic
    1. Start to contribute
    2. At the same time, try your luck as consumer
    3. After a number of successful consumptions, start to use the reciprocity algorithm
  - Other simple heuristics possible

P2PWNC Simulation

Simulation Model: Benefit, Cost

- Usage model
  - Users make CBR video-calls of fixed duration
  - Users issue receipts of fixed weight, normalized to 1
- Contributor cost
  - Do not model congestion
  - Cost generators
    - RF energy
    - Potential for security attacks
    - Metered connections
    - ISP Acceptable Use Policies
  - Assume cost linear to the number of allowed calls
  - Normalize to c = 1 unit of cost per allowed call

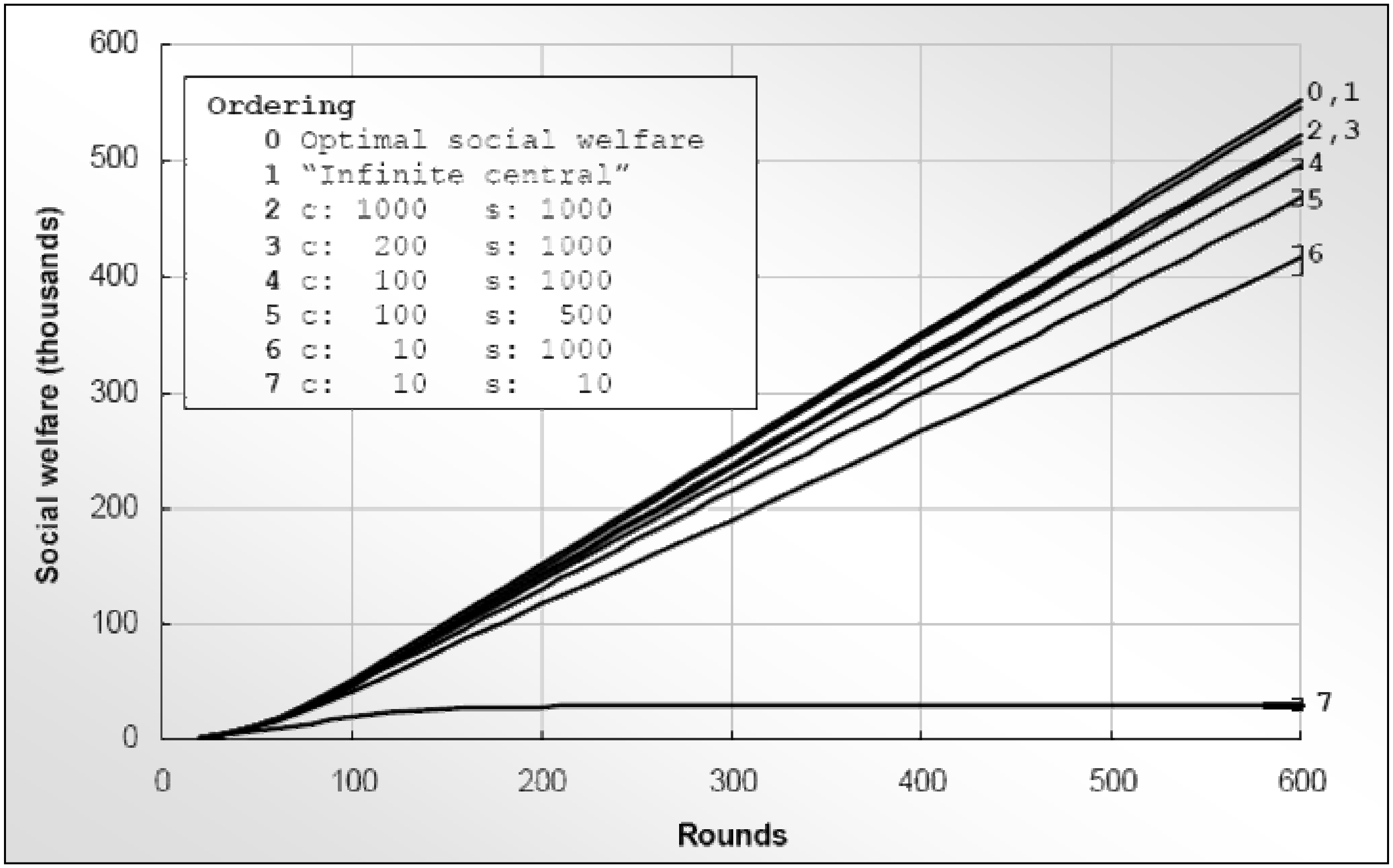


- Consumer benefit
  - User obtains b_{max} units of benefit per allowed call
  - Contributors can punish (reduce benefit) by **delaying login**
  - Contributors use SRM to judge
  - Assume a universal SRM-to-benefit function

Simulation Model: Rounds, Ratings

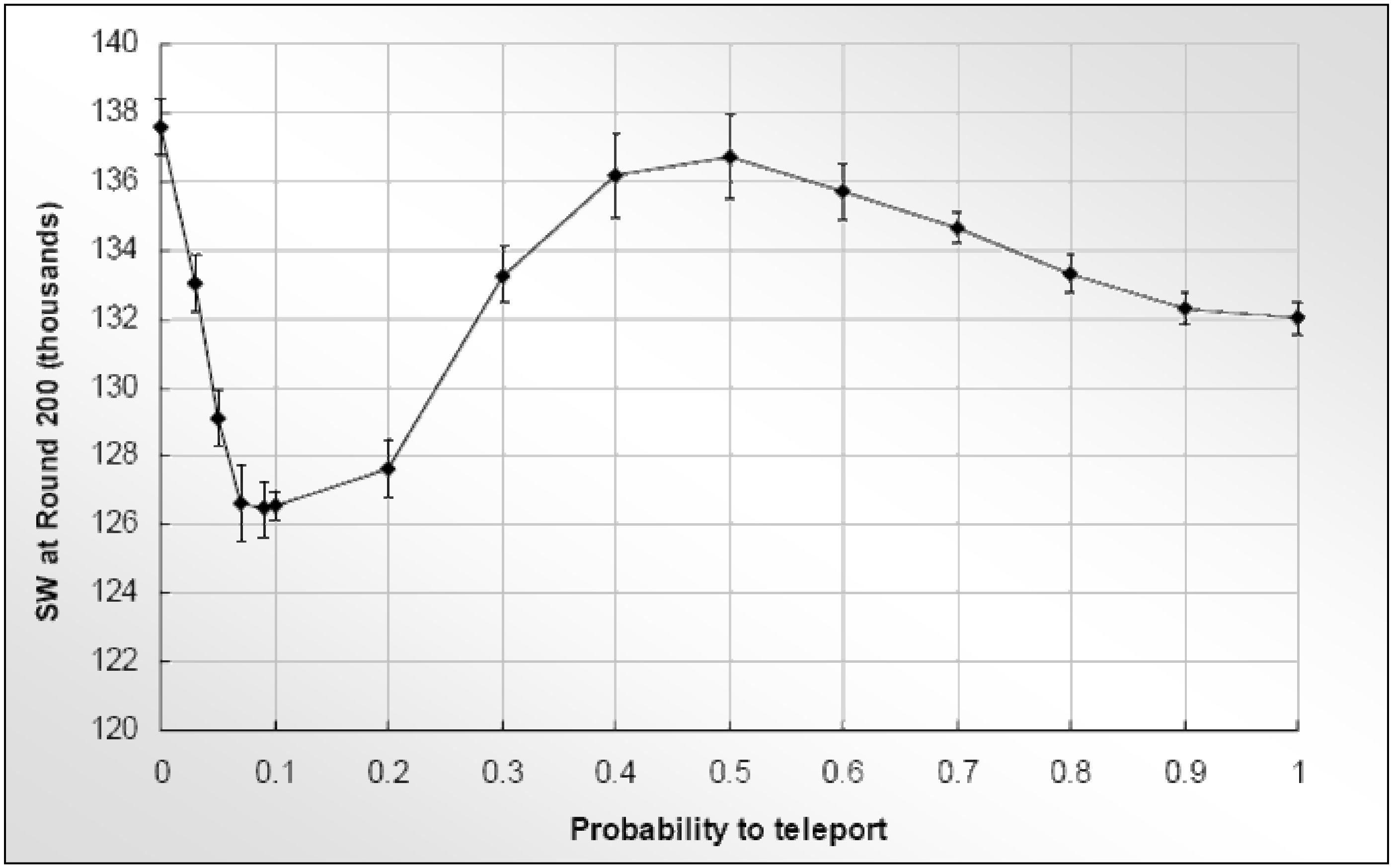
- Rounds
  - A match is the pairing of a consumer with a potential contributor
  - A round is a set of matches equal to the number of peers
  - 3 mobility models
    - **Perfect matching:** Each peer has one chance to consume, one chance to contribute per round
    - **Preferential visitations**
    - **Random waypoint**
- Ratings
  - Peer net benefit is total benefit minus total cost
  - Peer rating is the running average net benefit per round
  - Social Welfare (SW) is the sum of peers' net benefits
  - Optimal SW is the SW that would have been attained if every match resulted in b_{max} for the consumer and 1 unit of cost for the contributor
- Community growth
  - Peers join, up to a maximum number
  - Peers never leave

Cooperation vs. Information



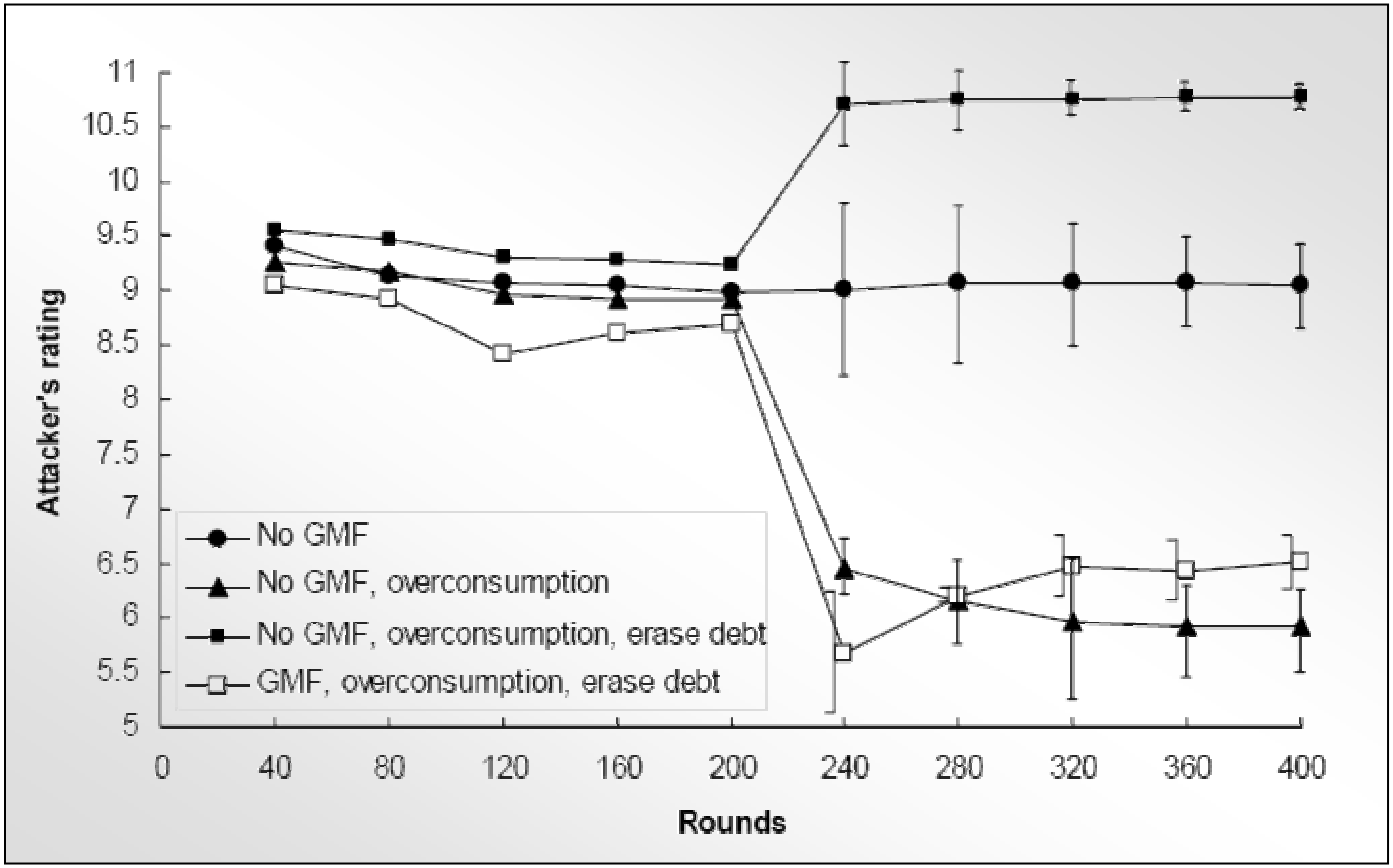
Maximum number of peers	**100**
Server repository size	**Variable**
Client repository size	**Variable**
Community growth	**1 new peer per round**
b_{max}	**11**
Mobility model	**Perfect matching**

Preferential Visitations



Maximum number of peers	**100**
Server repository size	**1000 receipts**
Client repository size	**100 receipts**
Community growth	**1 new peer per round**
b_{max}	**11**
Mobility model	**Preferential visitations**

The Need for GMF



Maximum number of peers	**100**
Server repository size	**1000 receipts**
Client repository size	**200 receipts**
Community growth	**All peers join at Round 1**
b_{max}	**11**
Mobility model	**Random waypoint**

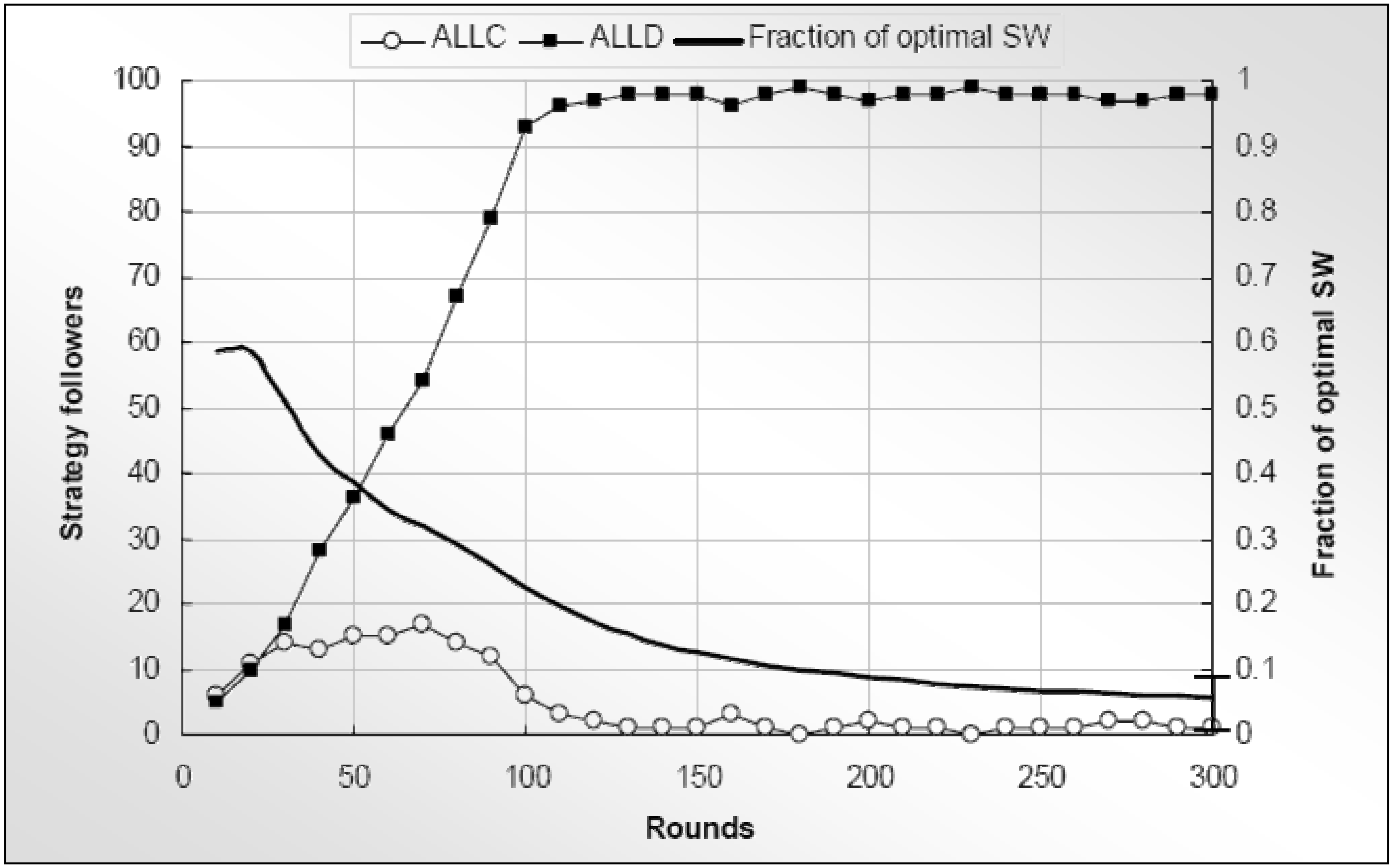
Simulation Model: Evolution

- Shortsighted rational, adaptive peers
  - Results from assuming non-tamperproof modules
- Define 4 strategies
  - RECI (RECIprocating)
    - The combination of the P2PWNC reciprocity, gossiping, and bootstrap algorithms
  - ALLC
    - Gossips like RECI, always cooperates giving b_{max}
  - ALLD
    - No gossip, never cooperates
  - RAND
    - ALLC or ALLD with a probability, starting at 0.5 and adapting
    - An 'under-provider'
- The rating of a strategy is a weighted average of the ratings of its followers
  - Weighted according to how many rounds they have been following the strategy
- An 'Internet-based' learning model
  - Learn with probability
    - Then jump to strategy with $p = 1 - \frac{rating_{OLD} + 1}{rating_{NEW} + 1}$
  - Mutate with a probability
    - Explore strategy set (perhaps under more favorable conditions)

Strategy Set: ALLC, ALLD

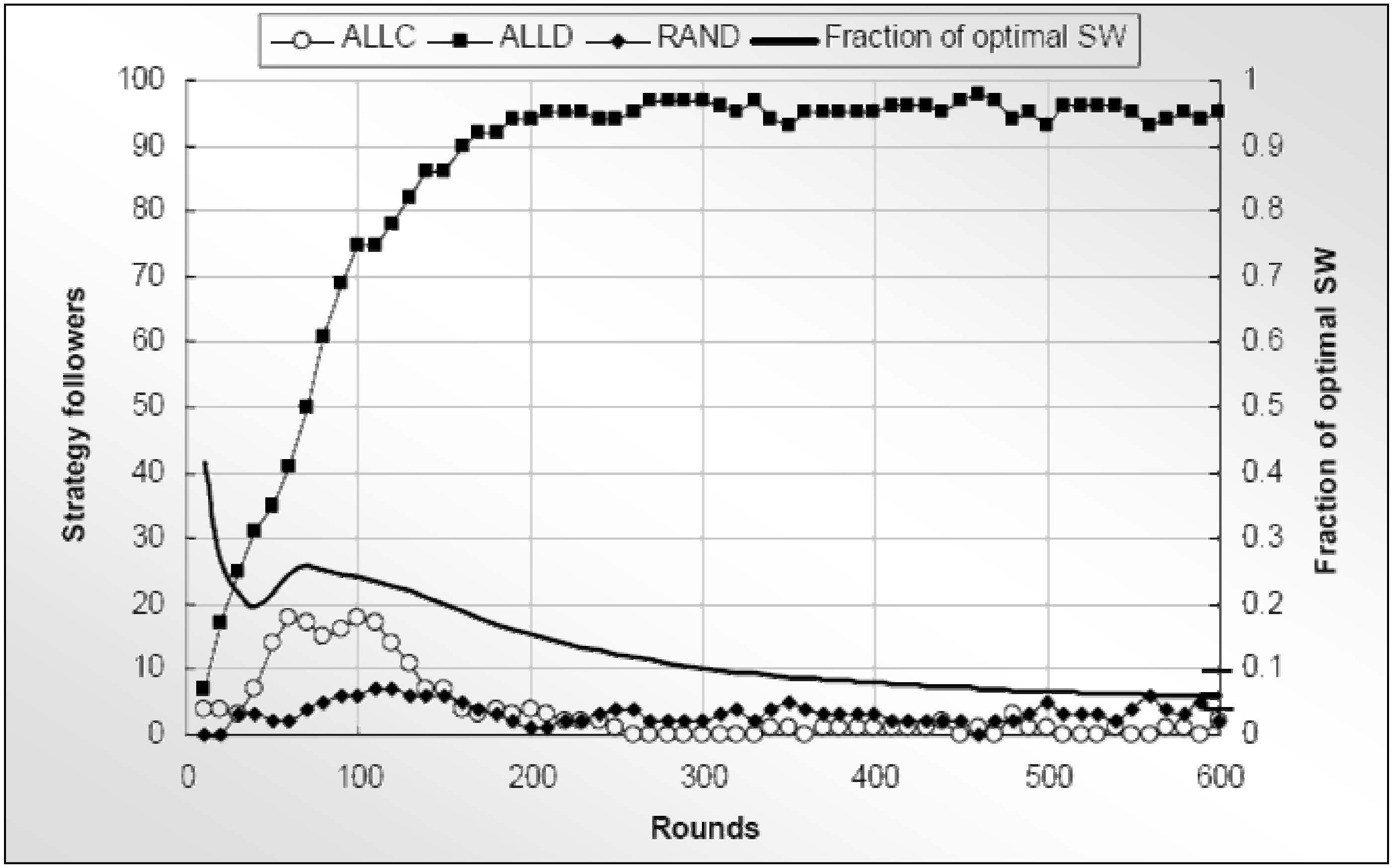
Maximum number of peers	**100**
Community growth	**All peers join at Round 1**
b_{max}	**11**
Mobility model	**Perfect matching**
Strategy mixture	**ALLDs and ALLCs**
Evolution	**No**

Strategy Set: ALLC, ALLD



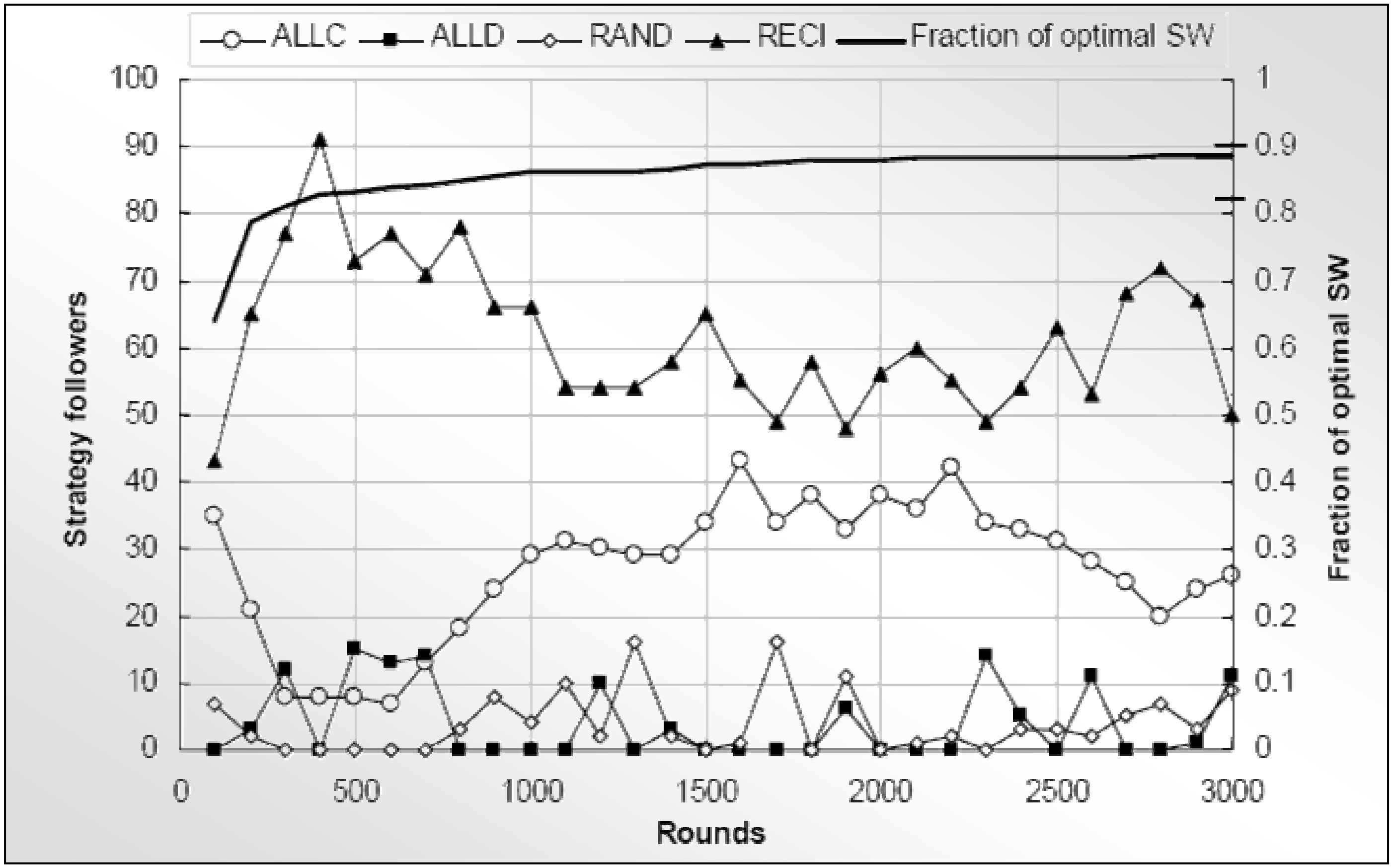
Maximum number of peers	**100**
Community growth	**1 new peer per round**
b_{max}	**11**
Mobility model	**Perfect matching**
Join probabilities	**50% ALLC, 50% ALLD**
Evolution	$p_l = 0.2$, $p_m = 0.001$

Strategy Set: ALLC, ALLD, RAND



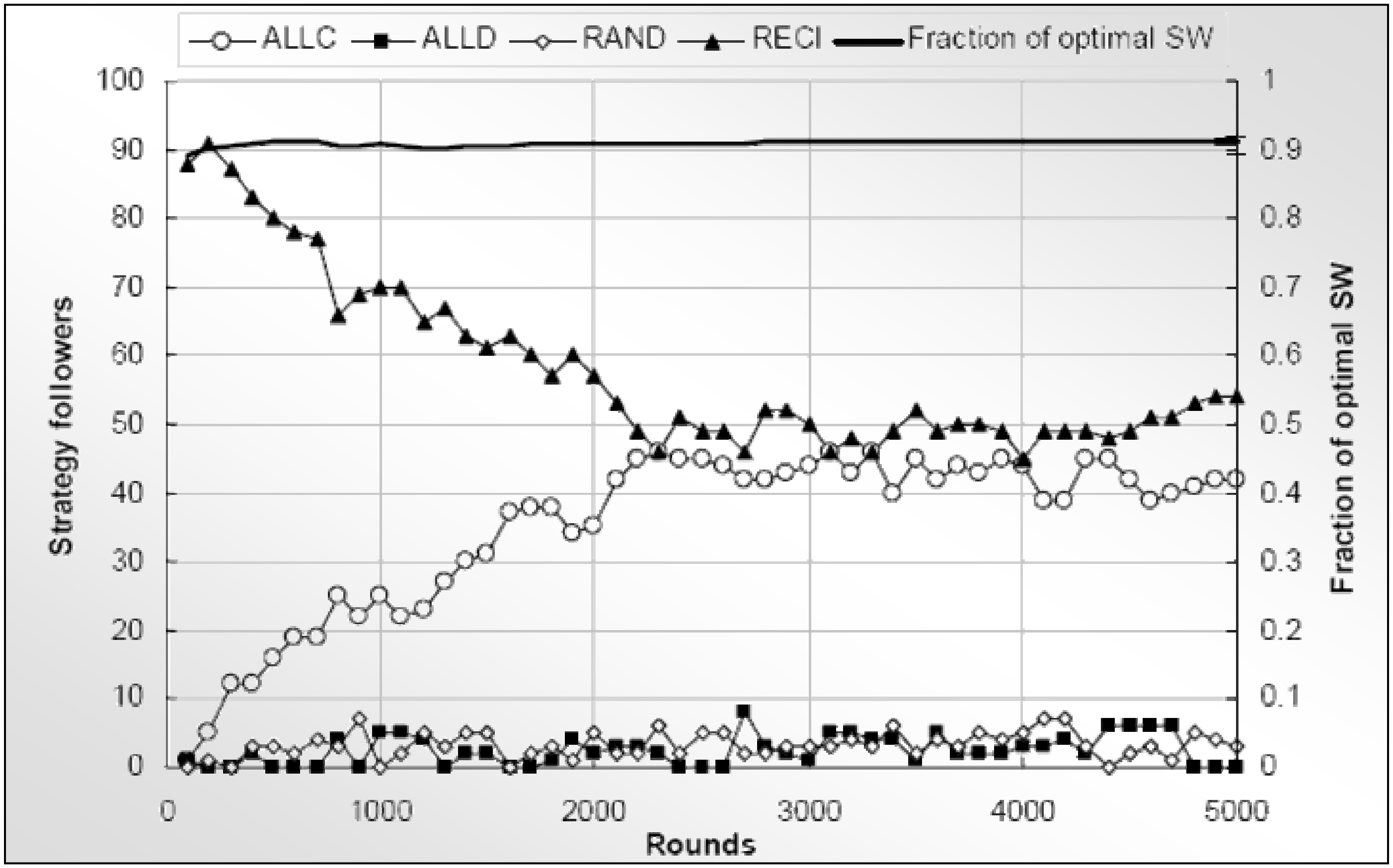
Maximum number of peers	**100**
Community growth	**1 new peer per round**
b_{max}	**11**
Mobility model	**Perfect matching**
Join probabilities	**33% ALLC, 33% ALLD, 34% RAND**
Evolution	$p_l = 0.2$, $p_m = 0.001$

Strategy Set: ALLC, ALLD, RAND, RECI



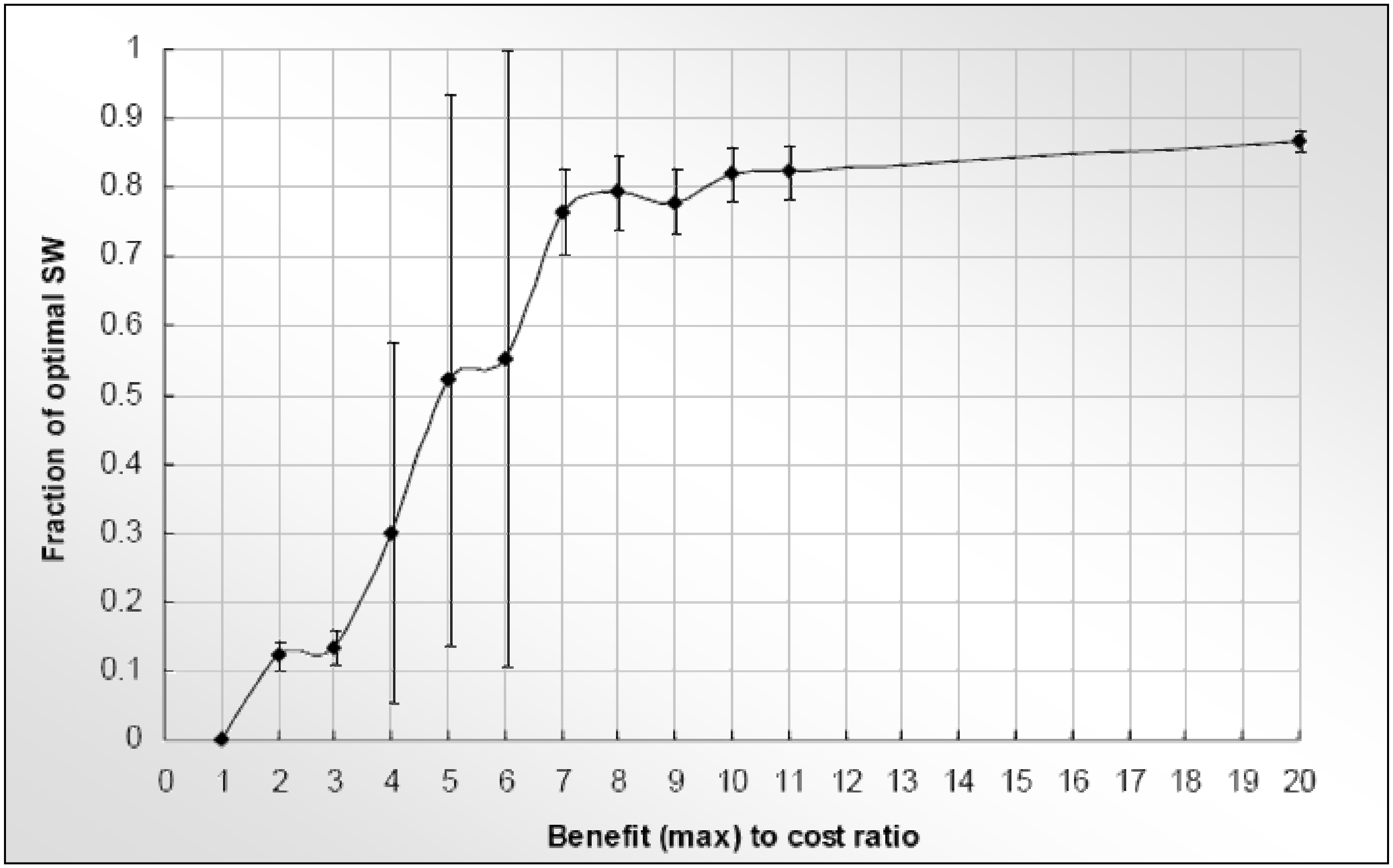
Maximum number of peers	**100**
Community growth	**1 new peer per round**
b_{max}	**11**
Mobility model	**Perfect matching**
Join probabilities	**33% ALLC, 33% ALLD, 34% RAND**
Evolution	$p_l = 1.0$, $p_m = 0.001$

Strategy Set: ALLC, ALLD, RAND, RECI



Maximum number of peers	**100**
Community growth	**1 new peer per round**
b_{max}	**11**
Mobility model	**Perfect matching**
Join probabilities	**100% RECI**
Evolution	$p_l = 0.2$, $p_m = 0.001$

Strategy Set: ALLC, ALLD, RAND, RECI



Maximum number of peers	**100**
Community growth	**1 new peer per round**
b_{max}	**Variable**
Mobility model	**Perfect matching**
Join probabilities	**25% ALLC, 25% ALLD, 25% RAND, 25% RECI**
Evolution	$p_l = 0.2$, $p_m = 0.001$

P2PWNC Protocol and Implementation

P2PWNC Protocol

- 7 messages total: 4 inter-team, 3 intra-team
- Support for both ECDSA and RSA signatures

```
CONN P2PWNC/3.0
Content-length: 164
Algorithm: ECC160
BNibmxStfJlod/LnZubH6pzWHQqKyZFcSMjnZurmTe4KjCRkllhV93MEegPvCsxz
2oe/hqevoPSrwO1JLO/36J8HTIeyeKQqTCfx+EPxweAvYC/ZFb8URLa2faIbvSgD
3lm6Wa1S4cYlSWeSNmFzS/ebDFfzakqNSEs=
```

Member certificate (Base64 encoded)

```
CACK P2PWNC/3.0
Content-length: 0
Timestamp: Tue, 16 May 2006 17:26:41 +0000
```

Session timestamp (RFC 3339 compliant)

```
RREQ P2PWNC/3.0
Content-length: 56
Algorithm: ECC160
Weight: 6336
BEXn8BHHViQ/YMyF2ny+KaI4YXz+W60uED7R8wZefDznyncfQKggzAc=
```

Relayed traffic thus far (bytes)

Contributing team public key

```
RCPT P2PWNC/3.0
Content-length: 272
Algorithm: ECC160
Timestamp: Tue, 16 May 2006 17:26:41 +0000
Weight: 6336
BNibmxStfJlod/LnZubH6pzWHQqKyZFcSMjnZurmTe4KjCRkllhV93MEegPvCsxz
2oe/hqevoPSrwO1JLO/36J8HTIeyeKQqTCfx+EPxweAvYC/ZFb8URLa2faIbvSgD
3lm6Wa1S4cYlSWeSNmFzS/ebDFfzakqNSEsERefwEcdWJD9gzIXafL4pojhhfP5b
rS4QPtHzBl58POfKdx9AqCDMBxRoGALKJSJYYXlsrwtiyZJKvPlU5B3lWrFuL25P
d+kv2iMVRElXk/4=
```

Signed receipt

Public Key Cryptography: Time, Space

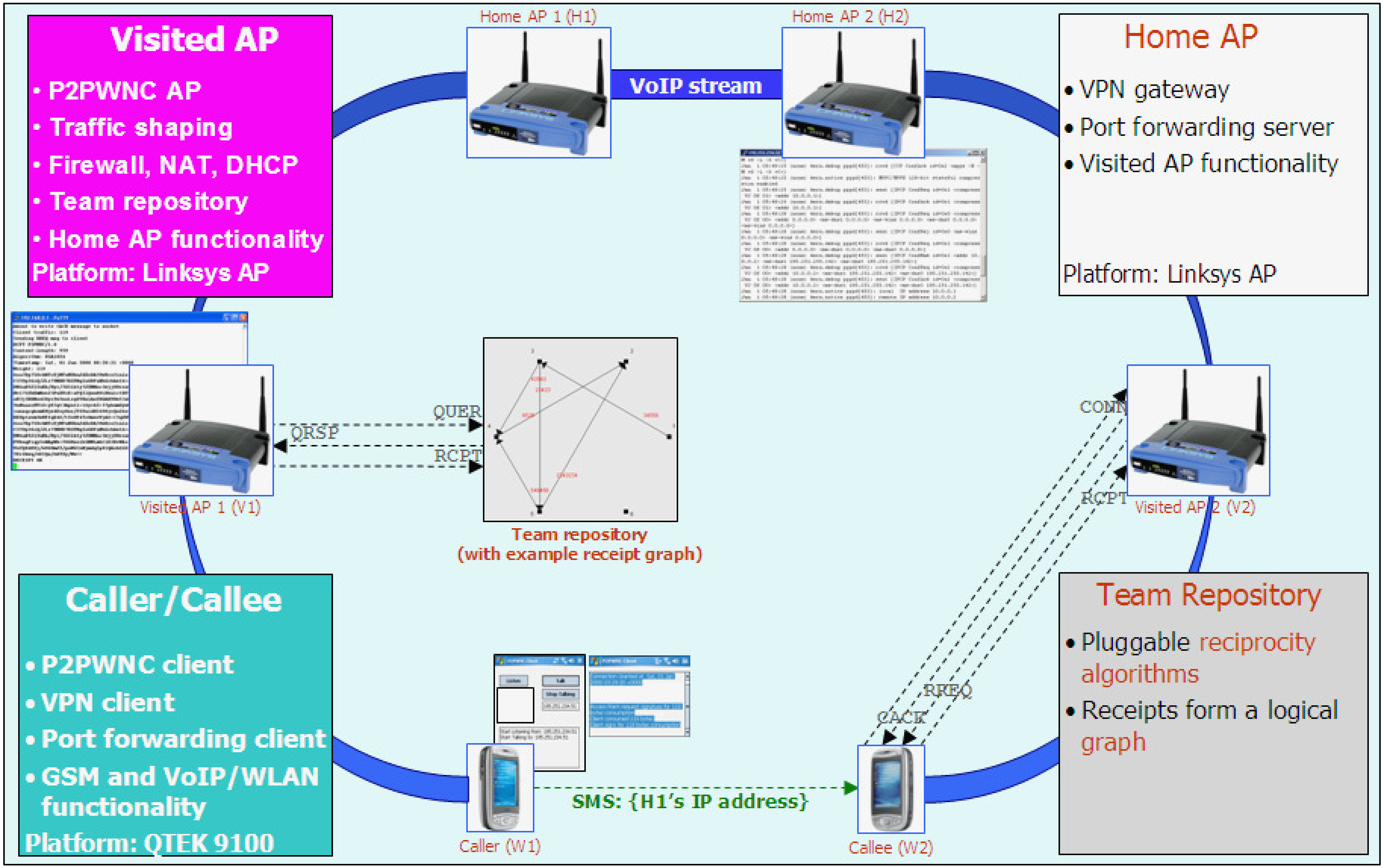
	Athlon XP 2800	Linksys WRT54GS
CPU speed	2.08 GHz	200 MHz
CPU type	AMD Athlon XP 2800	Broadcom MIPS32
RAM	512 MB	32 MB
Storage	60 GB HD	8 MB Flash, 32 KB NVRAM
Operating system	Linux kernel 2.4.18 (Red Hat Linux 8.0)	Linux kernel 2.4.18 (Broadcom specific)

RSA-1024 receipt **(bytes)**		ECC-160 receipt **(bytes)**
128	**Provider public key**	41
384	**Consumer certificate**	122
4	Timestamp	4
4	Weight	4
128	**Consumer signature**	40
648		**211**

Signing	Athlon XP 2800		Linksys	
Bit length (RSA/ECC)	RSA (ms)	ECC (ms)	RSA (ms)	ECC (ms)
1024/160	**9.0**	**1.3**	**300.6**	**20.3**
1536/192	**25.9**	**1.2**	**655.6**	**18.5**
2048/224	**47.3**	**1.4**	**1529.0**	**23.4**
3072/256	**149.1**	**1.7**	**3939.0**	**73.1**

Verification	Athlon XP 2800		Linksys	
Bit length (RSA/ECC)	RSA (ms)	ECC (ms)	RSA (ms)	ECC (ms)
1024/160	**0.4**	**6.5**	**12.3**	**114.7**
1536/192	**0.8**	**6.0**	**21.4**	**99.9**
2048/224	**1.3**	**7.1**	**37.9**	**135.7**
3072/256	**2.8**	**8.6**	**75.3**	**453.0**

Demo Setup



Visited AP
• P2PWNC AP
• Traffic shaping
• Firewall, NAT, DHCP
• Team repository
• Home AP functionality
Platform: Linksys AP
Home AP 1 (H1)
Home AP 2 (H2)
VoIP stream
Home AP
• VPN gateway
• Port forwarding server
• Visited AP functionality
Platform: Linksys AP
QUER
QRSP
RCPT
Visited AP 1 (V1)
Team repository
(with example receipt graph)
CONN
RCPT
Visited AP 2 (V2)
Caller/Callee
• P2PWNC client
• VPN client
• Port forwarding client
• GSM and VoIP/WLAN functionality
Platform: QTEK 9100
RREQ
CACK
SMS: {H1's IP address}
Caller (W1)
Callee (W2)
Team Repository
• Pluggable reciprocity algorithms
• Receipts form a logical graph

Closing Remarks

Discussion and Future Work

- P2PWNC and ISP Acceptable Use Policies
- P2PWNC and Wireless Community Networks
- Peripheral peers
  - Can expanded teams include them?
  - Or, factor location in receipt weight?
- Model mobility using cellular operator traces
- Model congestion
- Extend benefit-cost model (warm glow?)
- Handovers: how to eliminate QUER-QRSP roundtrip
- Collusion among teams, other adversarial strategies

Summary and Conclusion

- Proposed a P2P system for the sharing of WLANs
  - Fully decentralized
    - Open to all, free IDs
    - No super peers, no tamperproof modules
  - Rational participants
    - No overlay networks, no account holders
  - Minimal protocol
- Proof of concept
  - Promising simulation results
  - Implementation on common WLAN equipment
- Lessons learned
  - Generalized exchange economies are a good match for electronically mediated P2P communities
  - Each P2P community different: understand the users and the shareable good first (as well as the centralized alternatives)
  - Security and incentive techniques are intertwined

Thank you

Elias C. Efstathiou

Mobile Multimedia Laboratory
Department of Computer Science
Athens University of Economics and Business
efstath@aueb.gr

P2PWNC project page:

http://mm.aueb.gr/research/P2PWNC

Publications

Journal Article

[1] E. C. Efstathiou and G. C. Polyzos, Self-Organized Peering of Wireless LAN Hotspots, *European Transactions on Telecommunications*, vol. 16, no. 5 (Special Issue on Self-Organization in Mobile Networking), Sept/Oct. 2005.

Conference and Workshop Papers

[2] E. C. Efstathiou, P. A. Frangoudis, and G. C. Polyzos, Stimulating Participation in Wireless Community Networks, IEEE INFOCOM 2006, Barcelona, Spain, April 2006.

[3] G. C. Polyzos, C. N. Ververidis, and E. C. Efstathiou, Service Discovery and Provision for Autonomic Mobile Computing, 2nd IFIP International Workshop on Autonomic Communication (WAC), Vouliagmeni, Greece, Oct. 2005.

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