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CONTROLLED WI-FI SHARING IN CITIES: A DECENTRALIZED APPROACH RELYING ON INDIRECT RECIPROCITY

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Abstract- In densely populated cities, Wi-Fi networks-private or otherwise-are omnipresent. We focus on the provision of citywide broadband communication capability to mobile users through private Wi-Fi networks that are in range but belong to others. We form a club that relies on indirect reciprocity: Members participate in the club and provide free Wi-Fi access to other members in order to enjoy the same benefit when they are away from their own Wi-Fi network. Our club scheme does not require registration with an authority and does not rely on centrally issued club identities: Members create their own identities (public-private key pairs) and receive signed digital receipts when they provide Wi-Fi service to other members. These receipts form a distributed receipt graph, parts of which are used as input to an indirect reciprocity algorithm that classifies club members according to their contribution. We show that our algorithm can sustain cooperation within the club and is robust to attacks by free-riders. We implement and evaluate our proposed club algorithms on commodity Wi-Fi routers and dual-mode cellular/Wi-Fi phones. Because we anticipate that Wi-Fi telephony will be a popular club application, we present and evaluate a secure and decentralized architecture for citywide voice (and multimedia) communications that is compatible with our club both from an architectural as well as an incentives perspective.

Keywords- Wi-Fi, community networks, cooperation, decentralization, indirect reciprocity, Wi-Fi telephony.

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Introduction

The low cost and ease of deployment of Wi-Fi networks, combined with the fact that Wi-Fi operates in unlicensed frequency bands, has made Wi-Fi the technology of choice for local-area wireless connectivity in residential, corporate, municipal, and campus settings. Usually, Wi-Fi networks are also connected to the Internet over fixed broadband links. Today, the cost of fixed broadband is low, access capacity has increased, and Wi-Fi signals pervade many cities. However, most private Wi-Fi networks are security-enabled, and when users are away from their base they must usually rely on the more expensive cellular network for voice and data communications. In this paper, we focus on the provision of Internet access to mobile users through private Wi-Fi networks that are in range but belong to others. We present a club scheme that encourages owners of Wi-Fi networks to provide free Wi-Fi access to other club members that are in range, in order to enjoy the same benefit when they themselves are away from their base. With dual-mode cellular/Wi-Fi phones now available from many manufacturers, we propose that such a scheme can complement cellular networks in cities where Wi-Fi density is high. As mobile multimedia traffic is increasing, this scheme benefits both casual users (by lowering their cellular phone bills) and, in the long term, cellular operators (by allowing them to save cell capacity and charge a premium for other value-added ubiquitous connectivity services with quality guarantees). Here, in addition to focusing on casual usage, we mainly consider low mobility scenarios and do not concentrate on the real-time handoff of Wi-Fi connections from one Wi-Fi access point to another.

System Entities

In this section, we present the main club entities: members, receipts, and the receipt graph.

A. Members

We consider citywide Wi-Fi sharing clubs comprising thousands of members, each with a Wi-Fi network that provides coverage to specific publicly accessible areas. Each member generates a member identifier, which is a unique (with high probability) public key whose corresponding private key is kept secret by the member. We do not require a Public Key Infrastructure, and member public keys remain uncertified. Members will present their public keys when they request service.

B. Receipts and Receipt Graph

A club receipt is evidence that Wi-Fi service was provided. Receipts are generated according to a receipt generation protocol (see Section 2.2.1) everytime a member uses the Wi-Fi network of another member, and are sent over Wi-Fi to the Wi-Fi router that is providing service. Receipts consist of:

1. The public key of the contributing member.
2. The public key of the consuming member.
3. A time stamp, which notes the start time of the Wi-Fi session.
4. A weight, which notes the volume of traffic the Wi-Fi router relayed for the consuming member during the session.
5. The consuming member's digital signature, which is a hash of the four fields above, asymmetrically encrypted with the consuming member's private key. One can verify this digital signature using information on the receipt itself: the consuming member's public key.

Receipts form a logical receipt graph. The vertices of this graph are member IDs (public keys) and the weighted directed edges point from a consuming member ID to a contributing member ID. An edge's weight is equal to the volume of traffic the source consumed from the destination; that is, the weight of an edge is equal to the sum of the weights of the corresponding receipts, and the direction of the edge signifies an "owes to" relation.

Algorithms

In this section, we present the three club algorithms. These are: 1) the indirect reciprocity algorithm, 2) the gossiping algorithm, and 3) the club entry algorithm.

A. Indirect Reciprocity Algorithm

The indirect reciprocity algorithm guides the contribution decisions of club members who adopt it and use it on their Wi-Fi routers. For the following analysis, we disregard that member IDs are implemented using public keys: We only need to remember that each member ID in a club is unique. Note also that each receipt can be uniquely identified from the following 3-tuple: {contributing member ID, consuming member ID, time stamp}. A set of receipts defines a logical receipt graph G with the following characteristics:

1. The vertices in G represent member IDs.
2. G is a directed graph. A directed edge C →P exists in G if the source, Member C (Consumer), has obtained service at least once from the destination, Member P (Provider).
3. G is a weighted graph. The weight of the C→P edge is equal to the sum of the weights of the corresponding receipts. By corresponding receipts, we refer to all the receipts issued in the system that show C as the consumer and P as the contributor.

For the following analysis, when stating that "Member P cooperates with Member C" we mean that Member P provides Wi-Fi service to Member C. The result of this cooperative action will be the eventual generation of a new C → P receipt, with weight equal to the volume of traffic that P relayed for C during the session. This receipt then becomes part of the system, which results either in the creation of a new C → P edge if none existed before or in the increase of the weight of an existing C → P edge.

The idea behind the indirect reciprocity algorithm is to use the risk of exclusion as an incentive to encourage cooperation, and realize this by cooperating only with known cooperators. The problem then becomes how to distinguish cooperators from non cooperators.

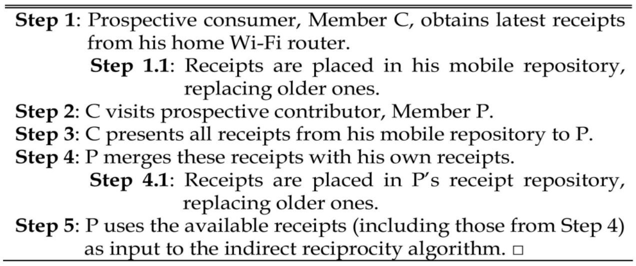
We introduce a metric, called Indirect Normalized Debt (IND). Its values range from 0 to 1, inclusive. Consider a prospective consumer, Member C, that requests service from a prospective contributor, Member P. P computes the IND to C by examining G. The closer IND is to 1, the more P "owes" to C according to IND. The closer IND is to 0, the less P owes to C. IND is the product of two factors, r1 and r2, which we present below.

B. Gossiping Algorithm

So far, we used the receipt graph as input but we did not specify where the graph is physically stored. Our club is fully decentralized with no authority to store its history. Also, the Wi-Fi routers of the members do not communicate with each other, and receipt repositories have a maximum number of receipts they can store.

If we did not introduce additional functionality, the following two things would hold true: 1) The receipt repository of a Member P would only contain receipts that showed P as the contributor; 2) The value of IND computed on such a partial view of the receipt graph would always equal 0 because without outgoing edges from P, maxflow and GMF return 0.

Table 2-



Step 1: Prospective consumer, Member C, obtains latest receipts from his home Wi-Fi router.
  Step 1.1: Receipts are placed in his mobile repository, replacing older ones.
Step 2: C visits prospective contributor, Member P.
Step 3: C presents all receipts from his mobile repository to P.
Step 4: P merges these receipts with his own receipts.
  Step 4.1: Receipts are placed in P's receipt repository, replacing older ones.
Step 5: P uses the available receipts (including those from Step 4) as input to the indirect reciprocity algorithm. □

Gossiping Algorithm

We introduce gossiping to disseminate receipts in the club in a practical and incentive-compatible way and allow members to have a less-biased view of the graph. We require that prospective consumers carry with them, in mobile repositories, a part of their receipt repository. More specifically, clients periodically request to be updated with the latest receipts from their home Wi-Fi router. The Wi-Fi router presents them the most recently acquired receipts from its receipt repository. Because a receipt can be as small as 130 bytes (see Section 5), a phone-based client can easily download and store thousands of receipts.

The second phase of gossiping involves the mobile client presenting receipts from its mobile repository to prospective contributors when the client visits them to request service. Assume Member C is requesting service from Member P. C has a clear incentive to show receipts from C's repository to P. These receipts, originating from C's Wi-Fi router, include receipts earned by C that show C as the contributor: If P were to consider these receipts as additional input to the indirect reciprocity algorithm, this can only increase $IND_{P\rightarrow C}$.

Receipts are then further disseminated throughout the club via the following procedure: P takes the receipts that C presented and merges them in his own receipt repository. Again, the standard rule concerning receipt replacement applies: If a new receipt is inserted in the repository when the repository is full, the oldest receipt is removed. In practice, this means that P would never include in his repository a receipt with a time stamp that is older than the oldest receipt in the repository-which, effectively, defines a time horizon for P, and encourages C to carry "fresh" receipts and, therefore, to also keep his Wi-Fi router in sharing mode in order to earn fresh receipts that point to C. P's Wi-Fi router would then also update Member P with the newest receipts from P's repository. Some of these receipts would have arrived via visitors and the gossiping procedure presented above. Member P, in turn, would present these receipts to the Wi-Fi routers that he visits, disseminating them further in the system. The algorithm is summarized in Table 2.

C. Club Entry Algorithm

New club members must first contribute to the club before they can consume. This is because the indirect reciprocity algorithm searches for direct or indirect debt from a prospective contributor to a prospective consumer. If the consumer is new and has never contributed before, he would be no different from a free-rider (he is owed nothing) according to the IND metric computed by the prospective contributor. Similarly, if the new member attempted to use the indirect reciprocity algorithm to guide his contribution decisions, he would find that all members appear as free riders to him: IND to anyone is zero because the new member has no outgoing receipts yet, either (he owes nothing).

Table 3- Club Entry Algorithm

```
Step 1: New club member, Member N, sets up a Wi-Fi router,
        chooses a patience value, sets $k = 0$.
Step 2: Member N provides and requests service.
    Step 2.1: As contributor, N provides service to anyone
              who requests it.
        Step 2.1.1: N stores the newly earned receipt in
                    his receipt repository.
    Step 2.2: As consumer, N requests service.
        Step 2.2.1: If service is granted, N issues a re-
                    ceipt and increases $k$ by 1.
        Step 2.2.2: If $k < patience$ go to 2, else go to 3.
Step 3: N exits club entry phase.
    Step 3.1: As contributor, N provides service guided by
              the indirect reciprocity algorithm. □
```

To break this deadlock, the club entry algorithm requires that, to join the club, a new member N starts contributing without executing the indirect reciprocity algorithm at first. (Member N can, however, use gossiping; that is, N's Wi-Fi router will conduct merging of receipts when a consumer requests service from N.) In parallel, we assume that the new member will start trying to consume service from the club. In the beginning, he will be unsuccessful: There will be no incoming receipts of the form X → N to show, and no such receipts will be stored by the prospective contributors either.

However, as soon as a receipt of the form X → N is earned by the new Member N, the probability that N can obtain service from the club becomes positive. In the receipt example above, if Member X, who consumed service from N and issued the X → N receipt, was also a good contributor, others that owed directly or indirectly to X will now also owe (indirectly) to N.

We specify a club entry heuristic: Each new member has a parameter called patience. As a new Member N attempts to consume from the club, at some point he will eventually be offered service and will issue a receipt (assuming of course he has started to contribute to the club using his Wi-Fi router).

As soon as Member N issues a number of receipts equal to the patience parameter, Member N leaves the club entry phase and starts to use the indirect reciprocity algorithm properly to guide his decisions. See also Table 3. The intuition is that after a number of successful consumptions, N deduces that he has become a known club contributor and that he can now select the ones he serves according to the result of the indirect reciprocity algorithm. If he tried to be selective earlier, he would hurt his own standing. On the other hand, if he never started to use the indirect reciprocity algorithm, he would continue to incur unneeded costs by potentially helping free-riders who offer no useful receipts (see also Section 4.4).

Receipt Repository and Indirect Reciprocity Algorithm Implementation

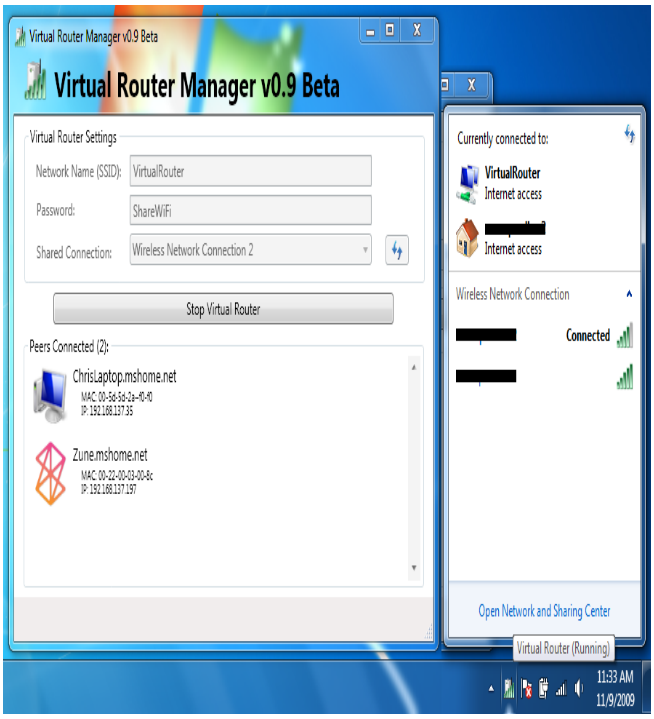
We implemented the receipt repository on the Wi-Fi router. For the execution of the indirect reciprocity algorithm, the Wi-Fi router needs to calculate maximum flows. For this purpose, a FIFO variant of the push- relabel maximum flow algorithm [2] was implemented. Its $O(n)^2$ worst-case running time is long, we, therefore, used the global relabeling heuristic [5], [4], which yielded dramatic performance improvements. We measured this performance for various graph instances. In our experiments, we created random directed graphs comprising 1,000 and 10,000 receipts (edges), and 100 and 1,000 members (vertices). Table 6shows the pure CPU time spent on executing the algorithm (measured with the Linux times function). Each reported value is the average time spent on the execution of the maximum flow algorithm for 20 random source-destination pairs of the same graph.

what is virtual router

Virtual Router is a free, open source software based router for PCs running Windows 7 or Windows Server 2008 R2. Using Virtual Router, users can wirelessly share any internet connection (Wifi, LAN, Cable Modem, Dial-up, Cellular, etc.) with any Wifi device (Laptop, Smart Phone, iPod Touch, iPhone, Android Phone, Zune, Netbook, wireless printer, etc.) These devices connect to Virtual Router just like any other access point, and the connection is completely secured using WPA2 (the most secure wireless encryption.) The Wireless Network create/shared with Virtual Router uses WPA2 Encryption, and there is not way to turn off that encryption. This is actually a feature of the Wireless Hosted Network API's built into Windows 7 and 2008 R2 to ensure the best security possible. You can give your "virtual" wireless network any name you want, and also set the password to anything.

Just make sure the password is at least 8 characters.

Unlike similar applications, Virtual Router is not only completely Free, but will not annoy you with any advertisements. Also, since Virtual Router is not ad-supported, it does not track your web traffic the way other ad-supported applications.



Virtual Router Manager v0.9 Beta

Virtual Router Manager v0.9 Beta

Virtual Router Settings

Network Name (SSID): VirtualRouter

Password: ShareWiFi

Shared Connection: Wireless Network Connection 2

Stop Virtual Router

Peers Connected (2):

ChrisLaptop.mshome.net
MAC: 00-5d-5d-2a-f0-f0
IP: 192.168.137.35

Zune.mshome.net
MAC: 00-22-00-03-00-8c
IP: 192.168.137.197

Currently connected to:

VirtualRouter
Internet access

[redacted]
Internet access

Wireless Network Connection

[redacted] Connected

[redacted]

Open Network and Sharing Center

Virtual Router (Running)

11:33 AM
11/9/2009

Fig.1-

Conclusion

As it stands, the controlled Wi-Fi sharing scheme that we propose attempts to balance a member's consumption with at least an equal amount of contribution. However, this may lower the overall value of the scheme for those potential members who live in areas of a city where there are not many visitors to serve. Indirect reciprocity favours symmetry between consumption and contribution, and homogeneity in the population. The more we depart from symmetry, the more our heuristics will fail to differentiate between a good cooperator and an attacker or free-rider, leading to a decrease of Social Welfare in the club. Using Virtual Router, users can wirelessly share any internet connection (Wifi, LAN, Cable Modem, Dial-up, Cellular, etc.) with any Wifi device(Laptop, Smart Phone, iPod Touch, iPhone, Android Phone, Zune, Netbook, wireless printer, etc.) These devices connect to Virtual Router just like any other access point, and the connection is completely secured using WPA2 (the most secure wireless encryption.) The Wireless Network create/shared with Virtual Router uses WPA2 Encryption, and there is not way to turn off that encryption. This is actually a feature of the Wireless Hosted Network API's built into Windows 7 and 2008 R2 to ensure the best security possible. You can give your "virtual" wireless network any name you want, and also set the password to anything. Just make sure the password is at least 8 characters. Unlike similar applications, Virtual Router is not only completely Free, but will not annoy you with any advertisements. Also, since Virtual Router is not ad-supported, it does not track your web traffic the way other ad-supported applications do/can.

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