# Sharing airtime with Shair avoids wasting time and money

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## ABSTRACT

*Shair* is a system allowing contracted mobile phone users to benefit from their unused quota minutes and text messages. Unused minutes and texts are shared via opportunistic local connectivity, allowing other Shair users to use sharers' phones within reach of short range radio such as Bluetooth.

## 1. INTRODUCTION

Mobile operators load up contracts with plentiful free minutes and texts to attract customers, secure in the knowledge that many will remain unused. At the same time, pre-pay users pay a high per-minute price for their network use, and can find themselves with too few pre-paid minutes remaining when they wish to make a call. Both sets of users would benefit if the contract users could sell their unused minutes to the pre-pay users for a mutually agreed price. *Shair* is a novel mobile application enabling this, allowing mobile users on contracts to sell their unused minutes and text messages to pre-pay customers when, e.g., they are running out of pre-paid credit.

For example, a pre-pay phone user Carol wants to make a mobile phone call to her friend Richard but she has too few minutes remaining. The Shair application running on her phone searches its environment using Bluetooth to discover sharers within range and finds two, Shirley and Sue. Using past history it knows that Shirley has been a reliable sharer (in fact, Shirley is a friend of Carol) but Sue is a stranger. Thus it connects Carol's phone to Shirley's using Bluetooth and invokes the Shair software on Shirley's device to make a call to Richard. The voice call will be packetized and transmitted as data traffic through the Bluetooth channel between these two mobile phones.

Pocket Switched Networks (PSNs) [5] are a kind of Delay Tolerant Network (DTN) [7] providing communication utilizing sporadic connectivity available between humans carrying mobile radio devices. This paradigm is currently an active area of research, tending to explore use of localized connectivity, e.g., Bluetooth, WiFi, to ship data via a multi-hop opportunistic network. A selection of routing strategies have been investigated, from naive strategies [22, 18] to complex approaches that exploit social information, periodicity of human movement, or geographical information [9, 13, 11, 10]. A lot of work has been done on fundamental issues in this kind of networking, e.g., understanding human mobility [5, 17] and forwarding. Applications are typically limited to those experiencing significant delays due to the multi-hop and intermittent nature of the connectivity, such as asynchronous messaging or email.

Shair is a novel PSN application allowing mobile phone users to share their unused contract minutes by using available PSN technologies. In comparison to other PSN applications, Shair eliminates the long-delay problem by only offering routes across two-hop paths, the first of which is an *ad hoc* hop whereas the second is to the infrastructure. As with other PSN applications, Shair explores local communication opportunities and uses historical social network information to select a suitable relay and predict the length of a connection [14]. We are in the process of building an implementation of Shair; in this paper, our aim is to propose a new application and to (hopefully!) engender discussion and reconsideration of the current mobile operator pricing schemes.

We proceed by motivating Shair (Section 2) and presenting its proposed architecture (Section 3). We then present data concerning two key feasibility aspects of Shair: human contact patterns giving rise to potential connectivity (Section 4) and a evaluation of call quality using a simple prototype (Section 5). Finally, we discuss three interesting issues pertinent to the deployment of Shair (Section 6) including the problem of operators wanting to block the Shair application due to the fear of lost revenues and the key security issues associated with Shair, and we conclude (Section 7).

## 2. MOTIVATION

It is well known that mobile operators attract contract customers by including excessive numbers of free minutes and texts in monthly plans. Most customers typically do not use up their contract minutes and so the operators benefit from guaranteed income without associated resource cost.

`Omio.com`[1] presents data showing that mobile phone users waste millions of pounds each month paying for text and talk minute packages they cannot use up. For example, one survey participant was on one of the most popular monthly plans in the UK, a "600 any network minutes and unlimited texts" tariff. This tariff costs £35 a month on an 18 month contract, equivalent to £630 a year. However, the survey revealed that they only used 250 minutes and 150 texts of their allowance. 47% of participants questioned were using less than half of their contracted minutes and 28% of users have unlimited texts as part of their monthly packages.

[*] This work was carried out while Pan Hui was at the University of Cambridge.

[1] `http://www.omio.com/staticpromo/press_release/tariff-survey.html`


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With more than 30 million mobile phone users in the UK on monthly contracts, this translates to millions of pounds each year being wasted on unused minutes and texts. The problem is exacerbated by the loyalty deals that many mobile phone companies offer existing customers at the end of their contracts to woo them into renewing their contracts. Typically, customers are offered additional minutes and texts as well as a new phone, rather than giving them money off their existing deals, leading to even more unused minutes and texts.

Another study by `moneysupermarket.com` showed that, on average, people with mobile phone contracts waste 912 inclusive texts and 19 hours 36 minutes of inclusive phone airtime each year. This is equivalent to an average of six months-worth of free minutes and four months-worth of free text messages.

Both studies suggest that customers should switch to lower tariff plans in order to save money, but there are two drawbacks to this proposal. First, users' monthly usage fluctuates and a cheaper contract with a lower level of provision can cause a user to end up spending more money if he overshoots his monthly limit. Second, the user sharing their unused minutes and texts will benefit more by trading their unused minutes and texts, particularly those on plans with unlimited text tariffs.

So, it is clear that there are many users with unused inclusive minutes and texts each month. As far as pre-pay or pay-as-you-go users are concerned, Table 1 lists the pre-pay price for minutes and text messages offered by the major operators in UK. We can see that the price for calling another mobile phone varies from 10p to 25p per minute, and a text message costs around 10p depending on the operator. As an example, consider the plan from above that includes 600 minutes and unlimited text messages. According to the survey contract users have, on average, 350 unused minutes. If we trade minutes for 10p and text messages for 5p, 350 extra minutes would generate £35. If we assume 200 text messages traded per month, that's an additional £10. Thus, the unused inclusive minutes and texts could generate £45 revenue, giving £10 profit over the original subscription cost of £35.

# 3. SYSTEM ARCHITECTURE

Shair is implemented by an application running on each participating mobile phone. This performs several functions: it discovers and establishes connections to other devices, maintains these connections, implements a charging scheme for usage, and provides a web portal as a configuration interface for users. This forms a general substrate for minutes and text sharing applications. We are implementing a community-based prototype called CamShair for use by students and other university members in Cambridge. CamShair will allow them to share their unused minutes as well as acting as a research tool for collecting data concerning human mobility patterns.[2]

## 3.1 User Registration

Users of Shair register and are identified by a combination of their email address and the Bluetooth address of their mobile phone. This aids traceability reducing the problems of freeloaders. The client software on the mobile devices provides usage accounting, recording the length of each Shair session and the corresponding Bluetooth address. After a Shair session the sharer either sends the usage record to the web server using SMS, or stores it temporarily on the device for uploading when better/cheaper connectivity is available.

Reputation schemes can reduce cheating in the system [16]. For example, users can report faults and cheats to the system and a user's credibility score will drop if reports about cheating are received. If a user's credibility score drops below a particular value, they will be blacklisted and connection attempts by them will be rejected. Users synchronize the blacklist onto their mobile devices while uploading usage reports, in addition to maintaining local black- and white-lists, specifying those they always and those they never want to share with. Such whitelists can also be created using domain reputation [20] ensuring only users from certain domains can connect to sharers. For example, CamShair permits only users from the domain `cam.ac.uk`.

There is an inherent privacy issue here in that users of the system become trackable. However, mobile phone users are *already* quite trackable by operators as they log calls and cell membership, and similarly, Bluetooth users can be logged by other Bluetooth users in their environment. The solution is, as always, for the user to control their use of the network, switching their Bluetooth or their phone off when they do not wish to be tracked.

## 3.2 System Configuration

There are two basic system configurations to consider when implementing the system on a mobile device.

- **Headset and Voice Gateway (HG).** In this configuration (Figure 1), the outgoing voice call is first converted to data traffic and transmitted through the Bluetooth channel between two local mobile phones, i.e., from mobile client to mobile server. The shared phone acting as the server then diverts the voice traffic to the cellular network via the phone's cellular link. In this scenario the shared device acts as a voice relay or gateway.

- **Phone and Service Monitor (PM).** In this configuration (Figure 2), the voice traffic is transmitted directly to the cellular network by the device making the call. In this scenario the shared device serves as service provider and monitor, securely granting the mobile client essential information such as its Subscriber Identity Module (SIM) card details, while monitoring the progress of the voice call via the local Bluetooth channel between the two devices. This can be achieved by using the Bluetooth SIM Acess Profile (SAP) [2], which defines the protocols and procedures that shall be used to access a GSM SIM card, a UICC card or an R-UIM card via a Bluetooth link. SAP was designed for devices such as car phones with built in GSM transceivers to connect to a SIM card in a phone with Bluetooth, so the car phone itself does not require a separate SIM card.

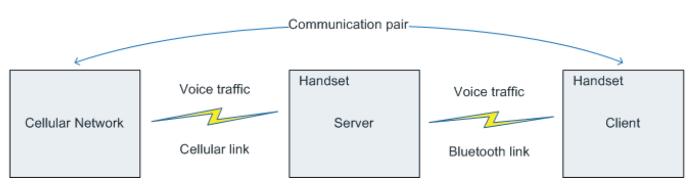


**Figure 1: Headset and voice gateway (HG).**

The PM configuration is the most desirable of the two for three reasons. First, voice quality is higher as it is transmitted into the cellular network as with a normal call. Second, potential communication range between the two mobile devices is dramatically larger: voice quality in the HG configuration only remains satisfactory if both devices are stationary and within 25 meters of each other

[2] `http://www.amillionpeople.net/`

| Mobile Provider | T-mobile | Vodafone | O2 | 3 | Orange |
|---|---|---|---|---|---|
| UK fixed lines and same network | 20p/min (first 2 mins) 10p/min (remainder of day) | 20p/min | 25p/min (first 3 mins) 5p/min (remainder of day) | 12p/min | 20p/min |
| Other UK network mobiles | 20p/min (first 2 mins) 10p/min (remainder of day) | 20p/min | 25p/min | 12p/min | 20p/min |
| UK text message | 10p | 10p | 10p | 12p | 10p |
| UK browsing | Max £1/day | Up to £1 for 15MB in a day, £2 for every extra MB | £3/MB | 50p/day or £5/month | Max £2/day |

**Table 1: Prepaid card offers by major operators in UK.**

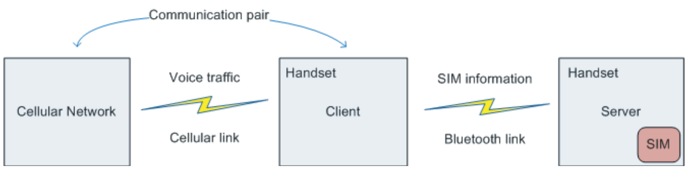


**Figure 2: Phone and service monitor (PM).**

whereas over 35 meters is possible in the PM configuration since it passes a smaller volume of data traffic over Bluetooth. Third, PM allows greater mobility of devices during a voice call as well as consuming far less battery energy as it uses Bluetooth less.

The significant drawback of PM is that the mobile client must deregister its own SIM and the mobile server must transfer its SIM identity to the mobile client before establishing a voice call. Both mobile devices thus lose their original identities during a call which is undesirable if there is an incoming call at this time. This problem does not arise in the HG configuration as each device continues to use its own SIM identity. This problem is somewhat addressed by the call waiting services typically provided by operators.

### 3.3 Shair Software Stack

There are several procedures required to support the core functions of Shair.

- *Device discovery.* Initiated by client, which may discover multiple sharers.
- *Operations and management.* Exchange of management information, such as the number of remaining minutes available from a particular sharer, used for sharer selection and authentication.
- *Call request.* The mobile client contacts the mobile server requesting placement of a call.
- *Call establishment.* The mobile server acts as a gateway to the cellular network, either for voice or SIM module, and the system establishes the calling process for the mobile client.
- *Airtime auditing.* Both the mobile client and server audit the airtime expenditure in real time during the conversation.
- *Call hang up and accounting summary report.* In the PM configuration, both the mobile client and server need to re-register their own SIM module upon disconnected in order to receive their own calls.

The Bluetooth protocol stack is divided into two layers. As Figure 3 shows, the Host Controller Interface (HCI) mediates access to the hardware layer, including the Baseband/Link Controller (LC) and Link Manager (LM), and is usually provided by the hardware manufacturing company. The protocols above the HCI form the software layer of the Bluetooth stack, and their interfaces are usually different and provided by different software organizations [4, 3, 19]. Fundamentally, Bluetooth protocols operate using the same communication and data exchange principles as the TCP/IP protocols. However, unlike the TCP/IP stack, the layers below the HCI in the Bluetooth stack cannot be completely hidden from the layers above the HCI due to particular application needs. For example, the Bluetooth headset profile specification places speech on a Synchronous Connection-Oriented (SOC) link, but establishing an SOC link needs direct access to LM. Similarly, the procedure of pairing devices in Bluetooth Generic Profile is also defined at the LM level. Implementation of Shair requires direct access to protocols at both upper and lower layers of the Bluetooth stack to realize functions such as synchronous voice transmission in HG and link encryption in PM, both of which use the LC and LM.

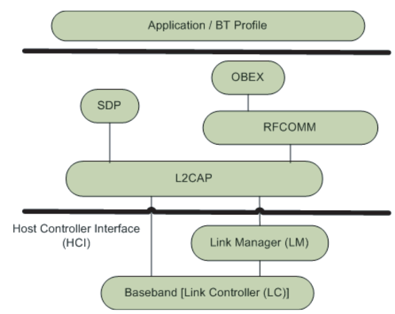


**Figure 3: Bluetooth protocol stack.**

## 4. HUMAN CONTACT PATTERNS

A key aspect of Shair's feasibility is that of human contact patterns, specifically human mobility, sharing opportunities and contact duration distribution for each contact opportunity. We have conducted several human mobility experiments using iMotes [5, 8, 12], a small platform designed for embedded operation, comprising an ARM processor, Bluetooth radio, and flash RAM.

The iMotes were configured to perform a Bluetooth baseband layer "inquiry" to discover the MAC addresses of other Bluetooth nodes within range, with the inquiry mode enabled for five seconds and with inquiry frequency every 120 seconds plus a jitter period drawn as a uniform random distribution from $[-12, 12]$ seconds. To analyse the feasibility of Shair, we use a dataset from a major computer communication conference, IEEE INFOCOM 2005. The iMote devices were distributed to approximately fifty students attending the Infocom student workshop.

Figure 4 shows the data on contacts seen by a typical iMote giving a qualitative view of contact patterns. We can see that this iMote has contacts with around 40 other iMotes out of the total of 50 participants. There are quite a lot of contacts during this period, many of which occur concurrently, i.e., contact with more than one device

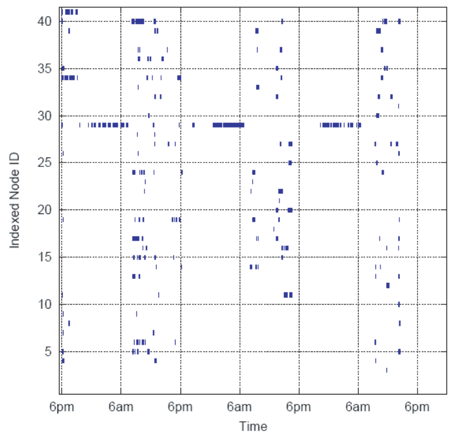


**Figure 4: Data on contacts seen by an iMote.**

at the same time. This demonstrates that there are many opportunities for making a Shair call. However, we must also consider the distribution of the contact durations, since if the contacts are too short they will not be suitable for making a phone call or even for establishing a Bluetooth connection.

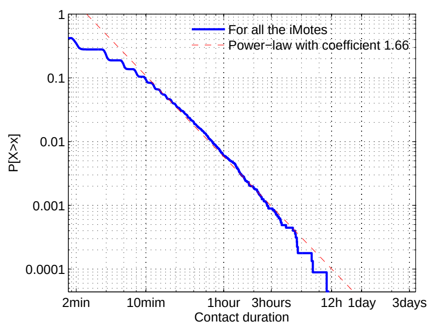


**Figure 5: Distributions of contact times for all pairs of nodes.**

Figure 5 shows the distribution of contact durations for all the iMote pairs in the experiment. We can see that for all pairs around 30% of contacts last longer than 2 minutes, and 10% are longer than 10 minutes. A 2 minute contact is sufficient for Bluetooth devices to establish a connection (typically this takes under a minute) leaving 1 minute for the voice conversation. Similar distributions are also observed for each typical individual pair.

It can be argued that 2 minutes is too short for most people to share minutes and make a phone call. However, considering the number of neighbors for each contact we see that, given there is one contact within range, there is a 40% chance of at least one other contact being within range, and a 16% chance that at least two other contacts are within range. This suggests that there is the opportunity to perform handoff to other contacts when the first sharer goes away. Finally, users' behavior can modify over time: the reputation system might promote those users that tend not to cut short sharer's calls.

We now consider the frequency with which a device meets other devices, determining the time a device must wait before encountering a potential sharer. In particular, we study the "inter-any-contact" distribution here where the "any-contact times" are the periods that nodes spend in contact with at least one of the iMotes. Only slightly more than 20% of the inter-any-contact times are longer than 10 minutes, so a node has an 80% chance of encountering another device in less than 10 minutes. We believe that this is a conservative estimate for the contact frequency since the iMotes were programmed to perform a Bluetooth enquiry only every 2 minutes, which would cause a lot of missed contacts.

These data support the feasibility of Shair application in terms of the frequency of local connection opportunities and the sufficiently long contact durations for a Shair conversation call.

# 5. EVALUATION

We developed a simple prototype of the system depicted in Figure 6. A laptop running Windows Vista functions as the voice call initiator, a PDA running Windows Mobile as the voice call gateway, and a fixed telephone as the voice call receiver. To make a voice call the laptop first makes a request to the PDA, sending it some basic information for making a call such as the contact number of the telephone. This invokes the dialer in the PDA to dial the received contact number of the telephone through the infrastructure. Once the connection is successfully established between the PDA and telephone, the voice connection through the Bluetooth channel between the laptop and PDA is established, and the voice call takes place between the laptop and the telephone.

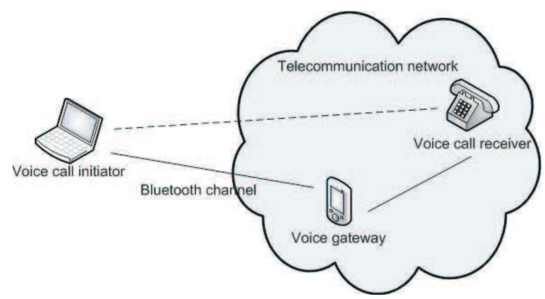


**Figure 6: A simple prototype.**

To evaluate end-to-end performance of this system, we observed the connection establishment time to the remote phone, which is the sum of the Bluetooth connection establishment time with the local sharer and the time to connect to the remote phone, and the perceived quality of received voice during a call in different environments. The connection establishment time is not significantly different from that of a normal voice call, but the device discovery process often takes more than 10 seconds depending on the environment.

We utilize the Mean Opinion Score (MOS) [15] to indicate the perceived quality of received voice, which is expressed as a single number ranging from 1 to 5, where 1 is the lowest perceived quality, and 5 is the highest perceived quality. Table 2 summarises the testing results of the voice quality with different distances between the phone and the laptop with both stationary and in motion setting. We can see that the voice quality is good or satisfactory within 25 meters of separation when both devices are in stationary or within 15 meters of separation when they are in motion regardless of whether there are intervening obstacles such as doors and walls.

# 6. DISCUSSION

A system such as Shair raises a wide range of interesting problems, from pricing minutes and texts to incentivising the opening of necessary interfaces on the mobile phone. We discuss three of the

| MOS | Quality | Impairment | WR (Stationary) | WR (Walking pace) |
|---|---|---|---|---|
| 5 | Excellent | Imperceptible | <20m | NA |
| 4 | Good/Satisfactory | Perceptible but not annoying | 20m–25m | <15m |
| 3 | Fair | Slightly annoying | 25m–30m | 15m–20m |
| 2 | Poor/Unacceptable | Annoying | >35m | >20m |
| 1 | Bad | Very annoying | not encountered | |

**Table 2: Perceived quality of received voice at different ranges.**

most critical here: how to price shared minutes/texts; how to incentivise operators against blocking Shair; and aspects of the problem of securing access to and through Shair.

## 6.1 Pricing Schemes

We propose two simple pricing schemes, but others are clearly possible and may lead to greater profits on the part of the sharers or even the mobile operators. The first scheme simply has a central Shair server set a uniform price for a shared minute and a shared text message. Each user consuming a shared minute or text message pays the sharer directly using, e.g., PayPal.[3] The second scheme has users buy electronic credits from the Shair server, and then undergo a reckoning at the end of each month. If there is disagreement between sharer and client in the record of time and texts consumed, then this will be flagged for later mutual resolution. If not, then credit is automatically transferred from the client to the sharer.

The first scheme has the disadvantage that a client may need to pay many other different users in the course of their usage, although all bills are settled immediately reducing the need for conflict resolution. In both schemes, if a sharer considers that a particular client is being unfair, they will add the client to a personal blacklist and also inform their friends. Such a user will typically be quickly ejected from the system via social gossipping of their status due to the famous “6-degrees of separation” phenomenon of social networks [21]. Incentivising sharing with respect to battery power consumption can be addressed separately [6].

## 6.2 Operator Incentives

A key objection to the Shair scheme is “but won’t the cellular operators lose money and thus try to stop such a scheme by legal/regulatory means?” Specifically, operators could add clauses to contracts forbidding the trading of free minutes and texts by subscribers. One response to this is that it could be very difficult for operators to detect and punish: unlike similar situations in other network applications where detection is straightforward as the traffic pattern of the illegal traffic is substantially different to that of the legal traffic, in Shair the “illegal” traffic is just more person-to-person voice calls and texts. Thus, distinguishing calls made on legal minutes from those on illegal minutes could be non-trivial.

A more positive approach is to turn the problem around: if operators support this scheme they could receive a percentage of the value of the resold minutes. They would thus gain extra revenue on minutes *that have already been sold*, while simultaneously increasing the value of their contracts to the customer. Increasing this value to encourage customers to sign-up to contracts is a key problem for current operators in markets such as the UK. Operators suffer from two key problems: the market is effectively saturated (it is already the case that there is $> 1$ phone per person on average in the UK); and the cost of customer acquisition is a considerable but necessary cost to the operator since contract customers are considerably more profitable than pre-paid customers. This latter point is exemplified by the current trend away from 12 month contracts toward 18 month and 2 year contracts. Allowing contract purchasers to recoup some of their contract cost could help to retain existing contracts. Simultaneously extracting further value from pre-paid customers often *precisely at the times when they cannot make calls as they have run out of pre-paid credit*. Furthermore, encouraging pre-paid users, who are typically light users, to become heavier users of the service is likely to increase revenues in the long-term and may even lead to pre-paid customers choosing to enter into contracts.

Finally, another situation in which the operator may benefit is that of roaming users. Roaming calls are currently very expensive to make and receive so many users simply turn their phones off or buy a disposable SIM. If roaming users can use Shair to make calls at a more reasonable rate, then both local and home operators can benefit from calls made that otherwise would not be.

Finally, sharing of minutes and texts is already common-place in some countries under some contracts. For example, several operators in the USA offer “family plans” where multiple users, e.g., a taciturn father and his garrulous teenage daughter, share from a fixed bundle of minutes and texts. In Africa, pre-pay customers can send airtime credit from their cellphones to another pre-pay customers [1]. The sharing enabled by Shair is based on the physical proximity of the users rather than a familial or prior contractual basis, but it is similar in principle: if sufficient benefit to the operator can be argued, there seems no reason why the operators would not want to encourage such a scheme.

## 6.3 Security Issues

The key security issues concerning the PM service are what to do to securely transmit SIM details to the client, and how to revoke the same details to prevent the client continuing to use them. These issues are resolved via the SIM Access Profile. In the SIM Access specification, security mode 2 or 3 and a passkey with length of at least 16 decimal digits must be used at the pairing; fixed passkeys are not allowed. The Bluetooth link between the client and server is always encrypted and the key length is at least 64 bits, ensuring secure transmission of SIM details. The SIM access client and server must be paired before they set up a SIM access connection and the server always authenticates the client. The information retained by the client is insufficient for it to continue using the server’s SIM after the server destroys the pairing.

The key security issue with the HG service is preventing the voice gateway from eavesdropping on the call. This issue is easily solved in the Bluetooth Headset Profile by using the SOC link. Analogously, in the Shair system we can guard against sharer-eavesdropping by connecting the audio system of a mobile client directly to the internal audio stream of the sharer through the SOC link.

Another possible concern about both schemes is that the sharer’s number will be displayed to the called party instead of the actual caller. In this case, systems using phone number as security verification identity may be abused. For example, certain banks use the phone number to verify your identity allowing you to you to acti-

[3] http://www.paypal.com/

vate your credit card by calling them from your phone. This can be addressed by using further information verification by the called party, already mandatory in most current systems. In the HG approach, this security concern can be solved by requesting the called party, e.g., the bank, to callback which has the added benefit that it saves the caller money.

### 6.4 Usability

Another issue of concern to users is that minutes are usually replenished once a month. As a result, some mobile phone users choose to ration their usage or save their minutes for important future calls. However, as users have already developed models of their monthly usage patterns, it seems unlikely that a user would mistakenly think he has hundreds of minutes left. In any case, users can always disable their Shair application. Even in the worst case that the user really has run out of contract minutes, they can still make it by either paying for the minutes or using Shair to access others' minutes. To prevent need for this, users can configure their Bluetooth profile such that every incoming connection needs approval.

## 7. CONCLUSION

To conclude, we have described a system architecture and prototype that enables mobile phone users to make better use of their existing contracts. The feasibility of the system was demonstrated using data collected from mobile phone user surveys, and from direct experiments using iMotes. By sharing unused minutes and texts, users can recover some of the cost they have wasted on the excessive provision in their monthly contracts. This could have a highly disruptive effect on the pricing of mobile phone connectivity. It also acts as a strong incentive for participation in the CamShair system which is intended to gather unprecedented quality data concerning human mobility patterns.

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