Sound Pryer: Adding Value to Traffic Encounters with Streaming Audio

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Abstract. We present a novel in-car entertainment application that is inspired by listening to music and the social interaction of manoeuvring in traffic. The Sound Pryer is a peer-to-peer application of mobile wireless ad hoc networking for PDAs with the intent of adding value to mundane traffic encounters. In essence it works like a shared car-stereo. Besides playing your own music, it allows prying on the music played by other Sound Pryer applications in other cars close-by. It accomplishes this during brief traffic encounters by peer-to-peer RTP multicast streaming MP3 music files. Through field trial we found that user appreciated the concept, but the prototype needs some improvements, foremost in terms of audio playback.

1 Introduction

The Sound Pryer concept is based on two appreciated activities: driving and music listening. It provides joint listening among drivers in everyday traffic encounters adding a novel flavor to the experiential aspects of traffic encounters. In essence, it works as a shared car stereo. A user can hear the tunes played on his or her stereo, but also eavesdrop the music played at other stereos, in vehicles close-by. Sound Pryer is an implemented peer-to-peer application of mobile wireless ad hoc networking for PDAs, streaming MP3 files via the Real Time Protocol (RTP) [14]. It draws on the idea that people take an aesthetic interest in the surrounding traffic and they would not mind sharing music, as they are practically anonymous to each other. More so, we argue that hearing other people's music will spark curiosity about them. Being able to determine who is playing and see that person would then further intensify the experience.

We present the implementation of a prototype we used in a recent field trial. The architecture draws on two principal technologies. The first is Wireless Mobile Ad Hoc Networking (MANET) [12], which allows connections between cars without any further infrastructure. Ad Hoc Networking only allows connections within the radius of its wireless range. This we use to approximate the participants of a certain traffic encounter, but as such encounters are brief we have developed a mechanism to quickly detect and establish connections. Second, the prototype relies on a peer-to-peer structure, which fits well with transient connections and unpredictable availability of remote peers in such networks. The field trial included 13 unacquainted users driving a five-kilometre route in downtown Stockholm. This constrained, yet realistic, approach gave insights concerning a range of issues, including driver's safety and privacy, and also on the design of the prototype and its performance. The trial demonstrated that the concept was entertaining, but not dangerously distracting. All users agreed that it was fun, however, also suggested improvements, especially on the audio playback. We will summarize the findings together with suggestions for such improvements.

The work presented here is of interest to MANET research. It is a novel application demonstrating where and how ad hoc networking is applicable. It is also of interest to the entertainment computing community as it prototypes a concept designed for a highly mobile situation. Driving could also benefit from safe alternative ways of entertainment.

2 Related Work

Eavesdropping in Sound Pryer relates to a similar effect in Sotto Voce [2]. It is an electronic guidebook application for handheld devices. The aim of this application is to augment museum visits. The idea is that users may select and play audio information. Other users may overhear that information item through their own device. Sotto Voice does not rely on streaming to disseminate the audio. Rather, it mimics eavesdropping by distributing indexes to clips. Consequently, each device is prepared with each sharable piece of audio clip in advance. The evaluation of Sotto Voce [7] is similar to the field trial we outline here. It was evaluated with 47 participants over four days in three museum rooms. First, each participant filled in a questionnaire covering basic questions, such as age and technological experience. They were then given a tutorial on how to use the guidebook. During the tour their conversations were recorded and in two of the three rooms there were video cameras to record their interactions. All events on the PDA were logged. Finally after completed the tour, which took about 15 to 20 minutes the couples were invited to a semi-structured interview. The evaluation showed that eavesdropping was an appreciated addition to electronic guidebooks. Moreover, it also proves that overhearing is interesting and joyful stimuli in socializing. ShoutCar [17] is a prototype to facilitate in-car music listening. It is designed with the mundane car-commuter, especially drivers, in mind. ShoutCar lets the user prepare a play list, which he or she then uploads to a web server. This page is then accessible through a customized browser. The browser reads out the items of the play list and the user may cycle through and select items he or she wants to hear using an input wheel. The design of the ShoutCar was iteratively informed by a group of car-commuters. It was found that many commuters actively entertain and *seek* alternative entertainment while driving. Finally, Sound Pryer relates to the FolkMusic [16] prototype. It is a mobile peer-to-peer application designed for face-to-face interaction that lets user share their play list items with other users close-by. A user may select to listen to any item on any user's play list as long as they remain within certain proximity. When a user selects such item it is streamed over a LAN. The proximity is determined using GPS positioning.

3 Design Rationale

The design of Sound Pryer draws on two broad ides: adding value to traffic encounter using personal technologies, yet honouring driver's safety through careful design.

3.1 Adding Value to Traffic Encounters with Music

The purpose of adding value is to entertain or at least to deepen the experience of a particular situation. Our goal is to add value to *traffic encounters*. It is a highly social situation in a public milieu. Traffic encounters involve people that are co-located on a stretch of road. They may comprise people in vehicles as well as people travelling by other means, such as biking or walking. The most prominent feature of traffic encounters is they are temporally bounded. The participants' high relative speed makes traffic encounters brief; often only enduring a few seconds. Still, some encounters, such as in caravans and inner-city traffic, are more persistent. Traffic encounters are often co-operative. In order to avoid accidents and disturbances, a driver is inclined to adjust their speed to maintain proper relative distance, but also to monitor and take action on other more delicate manoeuvres.

Keeping track of traffic encounters like this is also a pleasant experience. Donald Appleyard and Kevin Lynch argued, already in 1964, that the encounters are central in the road user's experience of driving. They claimed that: "[m]ost impressive of all is the motion of the accompanying traffic, to which he is forced to be attentive, and which even passengers will watch with subconscious concern [3]." We also argue the individual apprehension of a traffic encounters possesses in many cases the same qualities as what appealed to the 19th century flâneur. According to Charles Baudelaire: "He marvels at the eternal beauty and the amazing harmony of life in capital cities…He delights in fine carriages and proud horses, the dazzling smartness of the grooms…the sinuous gait of the women, the beauty of the children… [4]" Similarly, we suggest that from time to time drivers also take such interest in other people and vehicles in encounters. On the other hand, the brief engagements and the enclosing of the drivers in the hull of a vehicle occasionally make everyday life in traffic monotonous and lonesome. In such cases, many drivers are entertained by listening to music. For instance, in a recent study concerning the music listening habits of a group of music enthusiast, it was found that they listened to music 82 % of the time they spent in cars [5].

Our hypothesis is that, hearing what is being played in surrounding cars, even if it only means for a few seconds, would add a new dimension to the apprehension of traffic, beyond the glimpse of the identity of the individual driver and his or her vehicle, and therefore make driving more fun. It combines the experience of listening to music with interest in traffic encounters, which they have to attend to anyway. Thus to add value the Sound Pryer prototype must provide *joint listening* in traffic encounters. This requirement can further be divided into the following aspects:

- Responsiveness: First, the Sound Pryer must reflect well the prevalent traffic encounter and only include peers that seem part of it. This means the networking architecture must swiftly discover node re-configurations. This is most prominent when peers enter wireless range.

- Robustness: Second, when a particular network configuration is established the networking must be able to deliver the MP3 stream at an acceptable quality.

Finally, the prototype must also be able to provide means to help users *identify the source* of music to reflect the interest in the surrounding drivers and vehicles.

3.2 Personal Technologies

Road use is increasingly concerning mobile handheld communication technologies. For instance, more and more people feel it is important to always be reachable and therefore almost always carries a mobile phone. This, in turn, has made the car a popular, yet a controversial, place to make phone calls. It is not far fetched to believe that other handheld and personal computing devices will undergo a similar development. They will increasingly become part of people's everyday life and also accompany the person into the car. Therefore, we believe Sound Pryer staged on personal technology. The experience of Sound Pryer application use is related to the number of co-located users. This in turn is strongly dependant on the spread of it. To increase likelihood of achieving a critical mass of users we believe the importance of assembling Sound Pryer out of standardized (de facto or otherwise settled) and popular personal technologies. However, most currently available applications for PDAs are aimed at supporting work in office-like environments and are not adapted to in-car use. This is evident that most people would probably not bother performing the most fundamental actions such GUIs may require while driving. However, it is possible to design for PDAs to take driving into account, yet allowing *convenient interaction*. In the design of Sound Pryer we have let the following aspects guide us:

- Mounted PDA: First, having security concerns in mind, we do not argue for actually holding the PDA device while driving. On the contrary, in the car a handheld apparatus must likely be mounted at convenient range. As such, it is also easy to hook up the device with capability extending facilities, such as antenna, battery charging, and loud speakers.
- Modest interface: Furthermore, secure and driving-friendly interfaces must be largely audio-based. In this way the in-car interface minimizes the contention for visual attention which driving undoubtedly requires. Furthermore, it should be possible to apprehend the visual parts through quick glances. This means the interface must be uncluttered and "minimalistic".
- Automated operation: Finally, it must be largely automated, working without prompts for input, but letting the user gain control effortlessly whenever he or she finds adequate time.

4 The Sound Pryer Prototype

In order to meet the requirement of the joint listening we have developed an application for PDAs that supports two basic functions. They are *local play* and *remote play*. The local play mode works like a regular MP3 player, that is plays one item at a time from a list of files. The twist is, in local play, the current item is also broadcasted. Then in remote play, the user may hear the same item as some other player in local play, within a certain range, by capturing this broadcast. These two functions are then combined into *auto mode*, which automatically handles switches from local play to remote play whenever a peer first enters this range.

To meet the responsiveness requirement of joint listening, auto mode is implemented using two important technologies. The first is MANET technology. A MANET is defined as a self-organizing and transient network. Nodes in such networks do not rely on infrastructure, such as, base stations, routers, or DNS servers, to operate. Two nodes may communicate directly, using IP technology, if they are within wireless range, or indirectly via a chain of hops over intermediate nodes. However, such hopping would potentially contradict the responsiveness criteria and include peers not part of a particular encounter. Thus, Sound Pryer does not use multi-hop ad hoc networking. For similar reasons, in remote play a peer cannot capture via another that captures from a third part. However, any number of peers may capture the stream from a single source in range. Second, as Sound Pryer uses single-hop networking we can use the range of the transmitter to approximate the participants of a particular traffic encounter. That is if two peers are adjacent in the ad hoc network, they must also be close to each other physically. As high relative speed and limited wireless range makes nodes move out of it quickly, the window of opportunity for discovering peers is short. Bandwidth and energy conservation is really secondary to speedy discovery. Also traffic encounters concerns all nodes involved. This seems like a trivial statement, but in the light of previous work on service location this is a novel requirement. In SLP, Jini, and UPnP etc. it is assumed that discovery is one-sided i.e. only one party wants to find a particular resource. In Sound Pryer the discovery procedure must see to that all peers include all other peers. Sound Pryer accomplishes approximation with the Rapid Mutual Peer Discovery algorithm. (See section 4.1.1 for details.)

To meet the requirement of robustness we use the RTP to exchange MP3 files during encounters. The peer-to-peer model consists of each Sound Pryer being able to receive streams (via RTP client) as well as output streams (via RTP server) on a multicast channel. Auto mode arbitrates auto mode among a group of peers so that one peer will remain in local play and all the others switch over to remote play. The arbitration algorithm is an example of an exponential back-off algorithm, such as the collision detection protocol of Ethernet. (See section 4.1.2 below for details.)

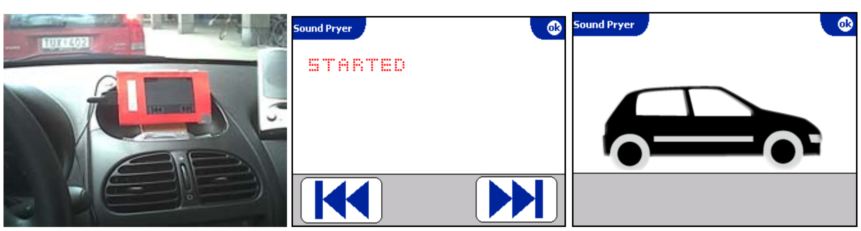

Fig. 1. The Sound Pryer Interface. A PDA mounted on the dashboard (left). Local play (middle). Remote play (right).

Finally, we have carefully designed the user interface balancing the requirements of identifying the source and on convenient interaction (See figure 1 above). First, as outlined above, auto mode is entirely automatic and thus fulfilling the automated operation requirement. Furthermore, auto mode is accessible to user via two screens, one for each play mode designed in manner suitable for driving, all according to the modest interface principle. The local play screen allows feedback through quick glances and some fundamental control over what the user is listening to. In the white space below the label ribbon Sound Pryer prints the title and artist name of the song if this information is available. The two large buttons (approximately 2 x 1 cm) allows the user to skip forward and backward one item at the time in the play list. The local play interface starts to play the current item on the play list where it was left off, e.g. in the middle of it, as soon it is activated. To stop music the user must exit auto mode, by pressing the 'ok' button in the upper right corner. The second screen is shown in remote play. We found through a series of Wizard of Oz [1] tests with various remote play screen designs, it was more constructive to provide only an impression of identification information than to include what music is being played. On this screen the whereabouts of the source of music is shown i.e. the vehicle colour and vehicle shape, such as sedan, station wagon, or lorry. To stop music from the remote source, a user must exit auto mode by pressing the 'ok' button.

4.1 Implementation

The Sound Pryer application is implemented in C/C++ interfacing the Pocket PC 2002 operating system API. The prototype runs on three sets of devices: the Compaq Ipaq 3760, the Compaq Ipaq 3850 and the HP Ipaq 5450. In the first two cases, Lucent Orinoco Silver WLAN cards running the IEEE 802.11 IBSS mode are used to accomplish single-hop ad hoc networking. In the latter we use the built-in WLAN card in IBSS mode. We achieve decoding of MP3 data by our own port of the publicly available LIBMAD MPEG Audio decoding library [11], to the Pocket PC 2002. We chose to port the LIVE.COM RTP stack [10] to implement the streaming operations performed in local and remote play i.e. the local play includes a RTP server and remote play includes a RTP client. The GUI of the auto mode relies on a Game API [8] for the Pocket PC 2002 handheld devices. It gives direct access to the video memory, which allows us to implement the full-screen landscape design.

Figure 2 below shows an overview of the software components in Sound Pryer. This figure also demonstrates the actions of auto mode in the case of two peers comes within wireless range of each other:

1. First assume local play is running on peer A.
2. The server module selects the current item of the play list. This item corresponds to a MP3 file stored at peer A.
3. The file is streamed to the multicast channel and simultaneously decoded and sent to the audio output module. Music begins to play by peer A.
4. At a later stage Peer A discovers Peer B through the RMPD algorithm and vice versa.
5. The RMPD module dispatches a notification of this event to the auto mode at both peers.

6. Auto mode initiates exponential backoff algorithm. Assume peer A wins the contention. It stops the server. Music playback stops at peer A, however, as Peer B loses the contention it continues local play.
7. The server dispatches a notification to the RMPD module, which then sends a message to peer B informing this decision.
8. The auto mode of Peer A starts remote play.
9. The RTP client dispatches a message to RMPD, which eventually informs peer B.
10. The client of peer A captures the stream of peer B. Music begins to play at peer A.

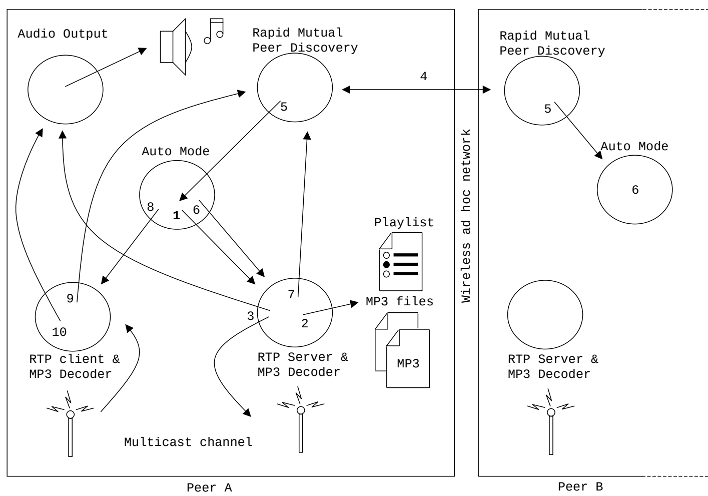

Fig. 2. The Sound Pryer Implementation

In the following sections we will closer examine the Rapid Mutual Peer Discovery and the exponential back-off algorithms of auto mode.

4.1.1 Rapid Mutual Peer Discovery

The purpose of RMPD is to discover peers in potentially brief traffic encounters. It is similar to AODV HELLO messages [13], but with important addition to accommodate mutual discovery quickly. The RMPD algorithm keeps a list of immediately accessible peers. Each entry in this list contains connectivity information, such as network identifier but also other properties to create an impression of who is providing music in the various user mode interfaces. Each entry is also associated with a timer. The entry is removed from the list when its timer expires. At a regular interval each peer announces its presence by broadcasting a HELLO message, containing the connectivity and auto mode data for that peer. When receiving a hello message from a peer present in the list, the timer of the corresponding timer is reset. Otherwise, an entry is created and appended. However, it would take x seconds before mutual discovery is established with HELLO message rate set to x seconds. To speed up mutual discovery a REPLY message is broadcasted whenever a new entry is inserted in the list. The REPLY message contains the connectivity information of the peer that is about to send it (A) as well as the connectivity information of the peer that was inserted in the list (B). When peers receive this message, they check the following condition: is A unknown and is either B present in the list (or is B this node)? If so, then the receiving node can safely assume it can reach peer A and appends it to its own list. However, it refrains from sending a REPLY message. Checking this statement reduces the complexity of the total number of message exchanged from $O(n^2)$ to $O(n)$, where n is the number of peers involved.

4.1.2 The Exponential Back-off Algorithm

The problem of arbitrating remote play among peers in auto mode, is similar to achieving distributed mutual exclusion [9]. To this problem most solutions are either centralized or distributed [15]. A centralized approach is inappropriate in peer-to-peer networking. Most distributed approaches requires reliable group communication, which is difficult to achieve in wireless ad hoc networking among peers in traffic, due to its extremely transient nature. Exponential back-off algorithms, such as the collision detection protocol of Ethernet, inspire our approach to this issue. The advantage such algorithm is that mutual exclusion can be resolved on each peer without any additional message exchange. This means that Sound Pryer has to keep less state and allows a much simpler architecture. The disadvantage is it may take some time before it is achieved. Basically, the exponential back-off algorithm we have developed for auto mode works as follows: whenever a peer goes into remote play, it waits a random time. If it experiences a failure, that is, there is a peer with a conflicting interest; it waits some more before attempting again. We define conflicting interest to mean the situation when two peers attempt to go into remote play simultaneously. The round-trip time, is the maximum time it takes for a single peer to detect an conflict, which we approximate by the sum of time it takes to stop local play and have RMPD disseminate that to other peers; followed by starting the remote play and having RMPD disseminate that too. Therefore when a peer wants to capture a stream it randomly picks a time slot. The first slot incurs no wait, the second means waiting one round-trip unit of time etc. In the first iteration a peer selects one slot out of two, in the second iteration, one slot out of four etc. For each iteration, when this time expires it checks whether there are any streams available. If this is the case, it stops local play and switches over to remote. If the peer is successfully able to capture, the other will fail and thus continue to stream through local play. There is still a possibility that the conflict will occur but it quickly grows improbable and hence the users are increasingly unlikely to experience interruptions.

5 Field Trial

To test the prototype and better understand the concept we organized a *field trial*. As we designed Sound Pryer to be used on roads among unacquainted drivers, most use situations will be brief and could take place anywhere along the vast road network. The likeliness for an encounter among a small set of unconstrained users is low. These factors constitute a methodological challenge when acquiring realistic feed back on user experience. Thus, we decided to conduct a field trial where the subjects use the prototype during a limited period of time in on a limited route. We conducted three separate trials, which engaged thirteen test subjects in all. We set up rendezvous locations along a circular route at suitable parking lots. The participants should stay unacquainted during the trial, and only meet during traffic encounters to best represent realistic situations. They drove about four laps at the same time, where each lap takes about ten minutes at the speed limit (50 km/h). This created a large number of events where the Sound Pryer concept could be experienced. The cars were equipped with a HP Ipaq 5450 handheld device and two loose speakers mounted on the dashboard. The device was prepared with their personal favourite music. All drivers were video recorded under the trial by a researcher sitting in the front right seat. The recordings were collected in order to pursue a careful analysis of their visible behaviour and increased out ability to understand their reactions as they take place. The drivers were also interviewed directly following the trial. The interviews were structured and all participants had to answer a list of questions.

5.1 Results

The field trial allowed us draw conclusions on two levels: the Sound Pryer concept and its prototype implementation. On the conceptual level we have found that joint listening among cars moving in traffic is clearly doable. First, wireless ad hoc networking is a promising technology for streaming MP3 music files with such intent. Second, we have good support in that users understood and appreciated hearing music from others. In line with this, we have found that giving an impression of the source of music through vehicle shape and colour gives is satisfying. Many users did understand and use the hints in their attempts to identify the source. Also, many users enjoyed this aspect. Although entertaining Sound Pryer does not seem dangerously distracting. The video analysis showed that drivers could attend it whenever the context allowed. For instance, sometime users seemed neglected it altogether because they where engaging in relative demanding manoeuvres, e.g. turning or co-ordinating with intense traffic. In the interviews a majority backed this by stating Sound Pryer did not interfere in their driving. Finally concerning the concept, it does not seem that Sound Pryer invades privacy. No users found it particularly intimidating to reveal the shape and the colour of the car. Furthermore, a majority of the users claimed they were willing to distribute music in the manner Sound Pryer demonstrated. The prototype we used in the test needs some improvements in order to better implement the Sound Pryer concept. First and foremost its audio reproduction must be improved, as no users were indecisively impressed with the quality. This concerns both streaming performance, such as removing any disturbances in the audio output, and concealing the back-off negotiation. Although the shape and colour hints of auto mode GUI were adequate in determine the source of music, some users also wanted some sort of help when looking out. This was obvious in situations when there were many similar cars around or very dark. Many users also asked for a control to go back to local play from remote play, when the music of the remote source was unsatisfying. Finally, in some events the range of the wireless ad hoc network did not really reflect users being in the immediate proximity. This happened for instance when it was dark or the source being obscured for some other reason.

6 The Robustness of the Prototype

As the quality of the sound reproduction in the field trial was somewhat disappointing we investigated the performance of the prototype in a lab study. In order to measure the robustness we decided to evaluate the impact of the bandwidth contention for the audio output at a single node. We measured the inter-arrival time of MP3 frames as they are delivered by RTP stack to the application. This is an important metric in streaming media performance, as late frames gives rise to audible gaps in the output and early frames waste bandwidth. However, late frames are not the cause for all disturbances in the output signal. The decoder may skip frames for other reasons, such as when encountering errors. In this particular case, we set up the test as follows. In the lab we placed six HP 5450 Pocket PC PDAs running Sound Pryer in manual mode. In the first test run we had one PDA stream a MP3 file and another capture it. We collected about a minute of data and noted our subjective impressions of the output quality. In the second run we activated the streaming at two PDAs and then activated capturing at the third. Both PDAs were streaming a copy of the file used in the first run. In total we performed five test runs in a similar fashion. In the file used each frame corresponded to about 100 ms of decoded music. On average, the frames are delivered with 30 to 20 ms margin, however occasionally late (or lost) postpones the arrival time. Consequently the standard deviation is about 35 to 50 ms.

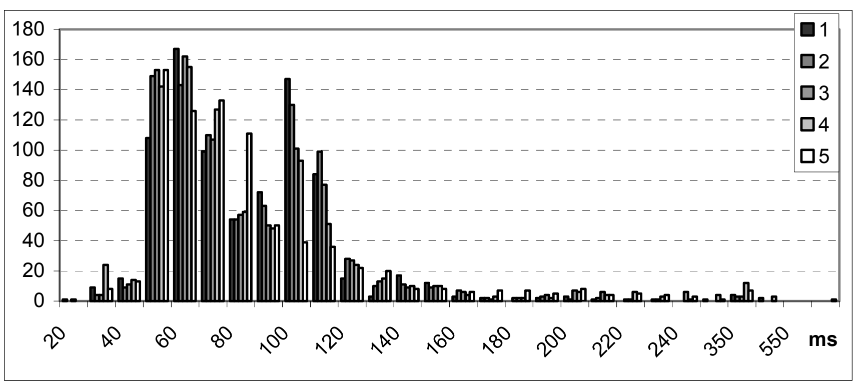

Fig. 3. Histogram of inter-arrival times for each run. To save space buckets left of 250 ms span 10 ms and to the right they span 100 ms.

Figure 3 shows the histogram of the inter-arrival times. There are two "spikes," the first at the (40, 80) ms interval, and the other at (100,120). Perhaps the first interval is caused due to RTP to compensate for very late frames. The second spike is a consequence of frame size. In the ideal case a frame should be delivered every 100 ms. The result of Figure 3 displays two, somewhat contradictory results. First, it seems that the average frame is delivered in time for play back independent of network load, which is desirable. Yet, there are also some exceptionally long delays occurring independent of load. The frame buffer may conceal occasional short delays for a while. In the case of too many delays, play back will consume the buffer before it is filled up and then disruptions become inevitable. Naturally, long delays will accelerate this process.

7 Conclusion and Future Work

The field trial showed that Sound Pryer was fun and safe on a conceptual level. The user's feedback and the lab test showed the prototype needs various improvements to better reflect the concept. First, in the current design, a user would hear his or her music come on and off at least one time before settling in either local or remote play. To improve the audio performance, the prototype needs to separate the switching of local and remote play in the auto mode from any actual audio playback. This concerns concealing the back-off negotiation and only interrupt local play when the outcome has been decided. Second, the prototype also needs work on the RTP streaming. The inadequate performance may be levitated somewhat with future, more powerful networking and PDA technology, such as quality of service guarantees and real-time operating systems. In the mean time we may somewhat approach the problem by increasing buffer lengths. However, this means actually hampering joint listening, as one party will be delayed a few seconds. Third, in terms of user interface, the prototype needs two obvious improvements. The firsts lies in the identification support. Users appreciated being able to receive hints on the source of music, but in some cases it was hard to determine it. Moreover, the opposite was it was also desirable, i.e. to know which users did receive music. To address this, a future design of Sound Pryer may include a lamp that light up the inside of the car, for instance, with a pale blue light. This would help users looking out to locate receivers and it would help user looking for sources. Third, user wanted some control to skip hearing a remote source. For instance, the remote player screen could include two controls, similar to the skip controls of local player screen, which lets user toggle all the remote sources including its own. Fourth, the prototype may also need work on the traffic encounter approximation i.e. using wireless range to determine the parties of a particular encounter. This may be accentuated by future wireless ad hoc networking technologies as they may provide very large range. Using positioning technology, such as GPS, we may calculate an appropriate range to better reflect the boundaries of a traffic encounters.

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