Interactive Phone Call: Synchronous Remote Collaboration and Projected Interactive Surfaces

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ABSTRACT
Smartphones provide large amounts of personal data, functionalities, and apps and make a substantial part of our daily communication. But during phone calls the phone cannot be used much beyond voice communication and does not offer support for synchronous collaboration. This is owed to the fact that first, despite the availability of alternatives, the phone is typically held at one's ear; and second that the small mobile screen is less suited to be used with existing collaboration software. This paper presents a novel in-call collaboration system that leverages projector phones as they provide a large display that can be used while holding the phone to the ear to project an interactive interface anytime and anywhere. The system uses a desktop metaphor user interface and provides a private and a shared space, live mirroring of the shared space and user defined access rights to shared content. We evaluated the system in a comparative user study. The results of the user study highlight the general benefits of synchronous in-call collaboration and in particular the advantages of the projected display and our developed concepts. Our findings inform future designers of synchronous remote collaboration software for interactive surfaces.

ACM Classification: H.5.2 [Information Interfaces and Presentation]: User Interfaces – Input devices and strategies; Prototyping.

General terms: Design, Experimentation, Human Factors.

Keywords: Personal projection, projector phone, phone call, collaboration, mobile phone.

INTRODUCTION
Mobile phones are nowadays used as pervasive interaction devices supporting a large variety of communication means, services and applications. Surprisingly, the original function of mobile phones, voice communication, didn't benefit from the services and features added to those devices in the last decade. We make frequent phone calls but while doing so it's difficult to use other applications available on mobile phones or to collaborate with the other party. As Gunaratne and Brush pointed out, there are many situations, when synchronous collaboration is desired during the synchronous voice conversation, such as sharing pictures or directions and scheduling appointments [7]. Currently, the only available means for remote collaboration are the usage of asynchronous file exchange protocols (e.g., sending of pictures via MMS or e-mail) or through the usage of central servers (e.g., using Facebook for sharing pictures). Moreover, it has been shown that within the intimacy and limited time span of a phone call, people feel more comfortable sharing private information than when sharing to the public, e.g. on Facebook [7]. Furthermore, operating the phone whilst in a call requires additional configuration or hardware, e.g., enabling the loudspeaker mode, which is not appropriate in every context, or usage of a headset or earphone.

In this paper we are going to explore the design space of synchronous remote collaboration between two parties during a phone call. Different from previous research on that topic [7], we don't require the user to use additional hardware like a computer or a headset. We present the Interactive Phone Call (IPC), which is a mobile application designed to support two or more calling parties in synchronous ad-hoc collaboration and data exchange during a phone call. Supported collaboration scenarios include, but are not limited to: sharing pictures, locations, directions, websites, presentations, and scheduling appointments. To provide for a usual call experience during collaboration, IPC particularly supports projector phones. Those mobile phones with built-in projectors allow the projection of a relatively large interactive display in front of the user while holding the device at one's ear as usually (Figure 1). IPC uses a desktop metaphor split up into two adjacent spaces, which can be

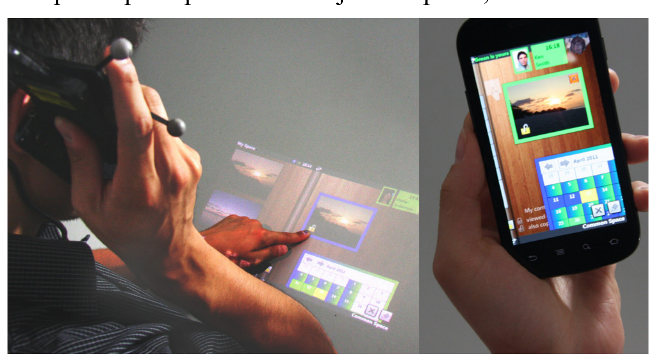

Figure 1: IPC modes.
Left: *IPC Projection,* Right: *IPC Screen*

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resized in favor of one or the other, in order to leverage the larger space to provide a more pleasant collaboration experience. The left side of the projection is used for a private view displaying personal data and applications available on the mobile phone. The right side is used for displaying a shared space, which is synchronized in real-time between both users. This allows instant sharing and interactive discussion of files and applications by moving files and applications from the private to the shared space. As all interaction happens synchronously, any annoying meta-conversations regarding the state of sharing become unnecessary. The IPC can be used with projector phones (*IPC Projection* mode, Figure 1 left), but as well on the screen of conventional smartphones (*IPC Screen* mode, Figure 1 right). Due to the smaller available display size in *IPC Screen* mode the user sees only the private *or* the shared space at a time and moves between spaces with a horizontal swipe gesture.

The underlying approach of the private and shared space of IPC is extended, among others, through concepts like *color based ownership coding*, showing which object belongs to which user, and *copy permission control* defining whether the other person can only see or can also copy and manipulate data from shared space.

After discussing related work, we present the IPC and its underlying concepts. Later on, we contrast the two different IPC modes (*IPC Projection*, *IPC Screen*) with another mobile in-call collaboration tool (*Screen Sharing*) that supports mobile screen sharing between calling parties with native phone software but without support for projection. Through a comparative study between *IPC Projection*, *IPC Screen*, and *Screen Sharing*, we compare the configurations with/without projection and with/without IPC concept. The results of this study highlight the advantages of the projection and the IPC approach in terms of larger screen space, better privacy control for sharing, and active loudspeaker mode not being required. Moreover, the study reveals the general benefits of remote synchronous collaboration support that is missing in contemporary systems.

RELATED WORK

The work presented in this paper builds on personal projectors and projection phones, direct interaction with personal projections, synchronous remote collaboration, collaboration via mobile devices, and privacy while sharing.

Personal projectors and projector phones

In the last 3-5 years we observed the emergence of pico-projector technology that allows the integration of personal projectors into mobile and wearable devices [13]. More recently the first projector phones, mobile phones with built-in projectors, appeared in the market. Prominent examples are the Samsung Beam, LG Expo and docomo PRO series SH-06C. This development has mainly been driven by the possibility to include pico-projectors with an acceptable power consumption and brightness. The envisioned usage scenarios focus mainly at the possibility to show pictures, videos, and presentations anywhere on any surface. The potential and challenges in terms of interaction design, privacy, and collaboration are not yet been addressed by currently available devices.

Direct interaction with personal projection

Rukzio et al. identified four conceptually different approaches to interact with personal projection: input on the projector, movement of projector, direct interaction with projection and manipulation of projection surface [13]. When considering the specific context of answering a phone call, then only the direct interaction with the projection can be considered as the projector phone has to be held close to the user's ear. The first to explore this approach were Karitsuka and Sato who used a shoulder-worn projector-camera unit that projected on a notepad held by the user [9]. The camera tracked the position of the user's finger on the notepad, which enabled touch-based interaction with projected information. The Brainy Hand system extended this approach by using the user's hand as the projection surface and a headset, which includes projector and camera [17]. Wear Ur World (better known as SixthSense) is a system worn as a pendant or head-mounted device which supports projection at any surface and direct pointing based interactions with the projection [11]. Other direct interactions were investigated were telescopic stick, a laser pointer or the user's boots [10] were used to control the interaction or where the user's forearm as the projection surface was used as the projection surface [8]. The interaction concept of the Interactive Phone Call is different from previously investigated settings as touch-based input on any projection surface (e.g. table or wall) is considered, as the user is holding the mobile phone with one hand close to the ear, and as only the remaining hand can be used for direct input.

Synchronous remote collaboration

Synchronous remote collaboration that goes beyond phone calls has already been investigated in the 1970s by Chapanis et al. and it has been shown that visual collaboration improves task completion measurably [5]. Since then we saw a very large body of research and commercial products in the area that often involves the usage of an audio / video link and live sharing of applications, documents and the desktop. Nowadays a multitude of applications such as Microsoft Lync, Windows Live Messenger, Adobe Connect, or Skype (screen sharing) are used.

Collaboration via mobile devices

The most research concerning collaboration with mobile devices focuses on co-located collaboration. Here several users e.g., interact directly with each other via a short-range network connecting their mobile devices to exchange files [2], use a public display as a mediator for the collaboration [12], or share their location information with others [4].

There exists relatively little research on synchronous remote collaboration between two users calling each other with their mobile phones. The PlayByPlay system supports collaborative browsing between two users whereby one is using a mobile device (e.g. calling and asking for directions) and the other one is using a desktop PC [20], which both are synchronized. The Newport system also supports collaboration between calling parties of which at least one person is close to a computer [7]. The users are able to send each other maps, photos, or notes that can be annotated but no live screen sharing is supported unless both persons sit in front of a computer. The commercial system Thrutu [21] enables in-call collaboration between smartphones but is designed for being used with loudspeaker mode on the mobile display. In contrast, both Newport and Interactive Phone Call (IPC) support collaboration during a phone call on a large shared display, but IPC provides distinct advantages as no desktop computer is required.

Privacy while Sharing

Mobile phones are considered as very private devices as they often contain information about personal communication (e.g. phone calls, SMS or email) and store private media. This has e.g. been addressed by the work of Garriss et al., which showed the importance of user privacy during mobile interactions with public kiosks [6]. MobShare is a photo sharing system for mobile devices, which considers privacy aspects carefully as it allows users to define explicitly with whom which pictures should be shared [14]. Ahern et al. confirm that people are in particular concerned about the pictures stored on their mobile phones when considering personal security and social disclosure [3]. Interactive Phone Call addresses this aspect via the private and public space. If the user wants to share a file then the user has to move it explicitly from the private into the public space.

INTERACTIVE PHONE CALL (IPC)

The IPC concept enables users to browse, share, and copy personal data and collaborate in real-time during phone calls. We added a synchronous collaboration channel to the voice communication to resemble co-located collaboration as closely as possible. We think that in this context the two most important qualities of co-located collaboration are that collaboration happens *synchronously*, i.e. actions of one person have an immediate effect on the perception of other nearby persons, and *bidirectionally*, i.e. all persons can manipulate the same objects at (almost) the same time.

To the best of our knowledge exists no solely mobile bidirectional collaboration system and therefore we looked at existing systems that support remote collaboration and data sharing with the help of desktop computers, such as Newport [7], Skype, Windows Meeting Space, Windows Communicator, Adobe Connect, and Cisco or VNC products. We found that these systems build on quite similar user interface concepts for sharing. The most prominent of these is that users have to choose between sharing their desktop/application and watching another user's desktop/application, sometimes with the option to take input control of the remote desktop. Another commonly found concept is sharing files asynchronously, peer to peer by means of Drag & Drop of iconic file representations. We were surprised how few existing systems support *synchronous* and *bidirectional* communication at the same time. Yet we are confident that the synchronous nature of calls demands for a fitting synchronous sharing experience. Otherwise the phone conversation would likely be cluttered with phrases like "Have you already sent the file? I didn't receive it.", "Have you already opened my file and see …", and "I have the file here, come and watch my screen". While this may be tolerable in traditional remote collaboration, mobile phone calls are often likely to happen on the go and last a relatively short time. Therefore, communication and collaboration has to happen as efficiently and effectively as possible.

Apart from how sharing is supported, in-call collaboration on mobile devices entails some more challenges specific to mobile phones. Among those are the considerably smaller screen space (even of a projection); the stored very personal data that is likely to raise privacy concerns during collaboration; and that mobile phones do not have a desktop interface (multiple parallel application windows) like PCs. The IPC should as well support user's mobility during phone calls, like when being at home, on the go, being able to project or being able to activate the loudspeaker, respectively.

Finally we wanted to explicitly support projector phones for the bigger display space they can provide which we assumed to be very beneficial for the task of co-located collaboration.

In the following we will present the IPC and its concepts, each including our design considerations and how they got reflected in the implementation. The last section will then present some apparent use cases supported by our implementation of the IPC.

IPC Concepts

Surface vs. Phone Metaphor

Computer and phone user interfaces developed quiet differently in the past according to their diverse usage requirements and the available screen space. While the WIMP (Windows, Icons, Menu, Pointer) metaphor, including Drag & Drop, became very widespread on computer operating systems, modern mobile OS at least abandoned the Windows, Pointer, and sometimes as well the Drag & Drop concepts. This holds true for projected interfaces of currently available projector phones, which just mirror the mobile interface. As the mobile phone offers more and more desktop PC functionalities, concepts for data, file, and object manipulation regain importance. An example is the Webtop framework on the Motorola ATRIX™ phone that resembles a standard WIMP desktop interface when connected to a bigger HDMI display [20].

Since users are more familiar with concepts for data sharing stemming from traditional computer operating systems, we decided to build on these by using a desktop-like interface. The mobile desktop shows a status bar, application icons, and title-less windows for every opened object or application (Figure 2). Every window can be moved, scaled, or rotated with Drag & Drop, Pinch to Zoom or two-finger rotate gestures. Content inside windows is mostly manipulated with single finger touches. Thus our interface builds on modified WIMP concepts as they are also used in current tabletop applications that, e.g., target multi-touch tables. Different from existing tabletop applications, we also allow the user to interact with the surface by just hovering over it.

Figure 2. IPC GUI: Ken and Lisa share pictures, maps, and appointments synchronously during the Interactive Phone Call.

This is for example used to display a close button on windows or hints on certain elements only when the user's finger is close to it (Figure 2 right middle).

Share and Copy between Private and Shared Space

The desktop space is further divided into a private and a shared space, which can be resized in favor of one or the other space with the divider in the middle (Figure 3a) to account for changing space requirements. The shared space is seen by all other call participants and synced in real-time, including window movement and content manipulation. Each participant can share windows by means of Drag & Drop from the private to the shared space, and copy windows in the opposite direction, if permitted by the window's owner (Figure 3b). The original window returns to its former place after it was shared or copied and an identical copy is created at the place where it was dragged.

The shared space on the right, mirrored between all call participants, makes it obvious, which windows are currently shared and how, even at which size-level, all participants currently view them. If permitted by the owner, content can be manipulated collaboratively in shared space and copied to the private space at any time at everybody's discretion.

The real-time synchronization further enables people to add visual communication like gestures to their spoken words as they would do with physical objects when co-located. If someone talks about a certain picture for example, they might point to it, grab and move it, or even point to certain positions in the image. Consequently, the concept of private and mirrored shared space avoids all asynchronous interaction during the synchronous phone call.

Ownership color coding

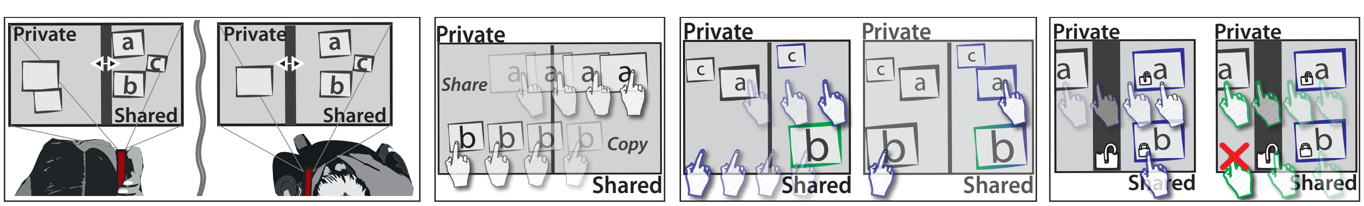
Giving the user feedback about which of the shown information belongs to them, the other calling party, or both is critical in sharing private data.

Different window border colors are used to show the origin and ownership of windows/objects. The own color is always the same, i.e. dark blue, whereas calling parties have different colors. Each window border can thus carry a number of different colors up to the total of call participants. When windows are dragged from private to shared space they receive a border in the owner's color (Figure 3c, Picture a). When windows are copied from shared to private space, the ownership of the person copying the window is added to the shared object, giving feedback to the former object owner(s) that the item has been copied (Figure 3c right).

Supporting Copy Rights and Privacy

Mobile phones store a lot of very personal data, e.g., emails, SMS, pictures, contacts, appointments. Making this data available for sharing is likely to raise privacy concerns. Thus giving users control over copy permissions and the granularity of sharing is important.

For IPC we differentiate mainly between three different types of sharing: *not shared*, *view-only* and *manipulate & copy*. The concept of private and shared space already serves the not shared type, as nothing is shared that is not explicitly dragged into the shared space by the user. The user can further toggle between *view-only* and *manipulate & copy* by opening or closing a lock button at the window's corner. The lock button is added to any window that may present private information when the window is dragged from private to shared space across the divider, inheriting the state of the default lock button that sits on the divider as initial state (Figure 3d). As the names suggest, the window can only be moved and changed in size and rotation as long as the lock is closed and freely manipulated, including content, and copied when the lock is open.



a) Resizable private & mirrored shared Space
b) Share & copy via Drag & Drop
c) Ownership color coding
d) Default & individual copy permission

Figure 3. Interactive Phone Call concepts

Unfortunately, the *spaces* and the *lock* concepts cannot serve every situation adequately. A calendar for example has to show many individual appointments in one window at the same time, which means they can only be shared all together or not at all. We think that these cases can be best solved individually from one content type to another. A calendar window, for instance, can have an additional details button that can be toggled in private space to influence shared space. When the button is off, only free/busy is shown in shared space without any further details about the appointments (Figure 2 left). In fact, a *details* button is able to solve a lot of privacy issues, but probably not all of them.

Supporting Freehand Annotations (The Pencil)

Despite support for real-time mirroring of the shared space, some information can be much better visualized with the help of freehand-sketched annotations. Therefore, all call participants can activate a pencil to draw on top of the whole shared space in their respective color. This way content such as maps and pictures can be annotated or freehand drawings can be painted on the shared space.

Phone and Call Status

The IPC software supports features similar to the standard call application. It shows the phone's status bar (battery, signal strength, etc.) at the top of the private space and all call participants by gender-aware icons, names and contact pictures. Starting calls from the contact list within the application is supported as well as ending calls by clicking on the red receiver icon on top of the other calling party, which is revealed as soon as the finger hovers over it.

Stateful space

Mobile Phone calls are inherently fragile. The connection can drop when one party moves, loses network coverage, or a phone runs out of battery. Social circumstances can disallow continuing the conversation. During a conversation supported by IPC, lots of data and annotations can be created in the shared space that must not be lost by accident. Therefore, if a dropped session is reopened, the participants are asked whether they want to continue their old sharing session or start a new one. Without another connection however, the shared space cannot be accessed to not undermine the privacy rules of other call participants, who intended showing their content only for the time of the call. Therefore, content the user wants to store persistently has to be copied to the private space before the end of the call.

Switching IPC Modes and States

An Interactive Phone Call can be in one of several states (sharing or not sharing), modes (*IPC Projection*, *IPC Screen*, or *Non-IPC*) and configurations, which result from multiple users collaborating in different modes.

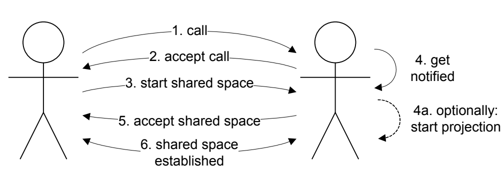


Figure 4: IPC states. Handshake before sharing starts.

IPC States

Apart from call support, the IPC software can also be used without an ongoing call to use the larger projected touch surface to interact with personal content. When a call is coming in (Figure 4, 1), it is visualized on the projection and can be answered from there (2). Once answered, the iconic representation of the other calling party is placed on the shared space of both users. However, the shared space is greyed out since sharing content may not be the intention of any call participant. To enable content sharing, one calling party must click the large "Start common space" button that covers the shared space (3). When clicked, the other party receives a unique notification (vibration or audio) (4) to indicate that she must take action to either accept or deny the sharing request that is presented on the shared space; this might require switching to *IPC Projection* or *IPC Screen* mode (4a). This initial handshake about sharing prevents unknown callers from presenting inadequate content without prior consent. Once the request is accepted (5) the shared space is established (6) and participants can share content until the end of the call.

IPC modes

Today, most people still telephone by holding the phone close to their ear. Despite alternative options as loudspeaker mode or the usage of hands-free accessories, the advantage of the original telephone behavior is that it does not require additional hardware like a headset, which may not be available at the moment or has run out of battery. Further it is much more unobtrusive than loudspeaker mode and can be used in relatively noisy environments. We think a projection can serve many circumstances where loudspeaker mode is no considerable alternative. However, there may be situations where this is vice versa. Therefore, IPC supports both *Projection* and *Screen* mode and seamless switching in between. Since the current mode affects the available space for sharing, these state changes have to be accounted for during calls as well (see next section).

In total IPC knows three different modes it can operate in as depicted in Figure 5. The user can cycle through modes by pressing the projector hard button on the side of the phone, which current projector phones such as the Samsung Beam offer.

In *Non-IPC* mode, the IPC software runs in background, only, and listens for button presses and sharing requests. The *IPC Projection* mode shows the IPC user interface described earlier on the projected display. The user holds the phone to her ear and interacts with the projection with her free hand. For the *IPC Screen* version, where the phone

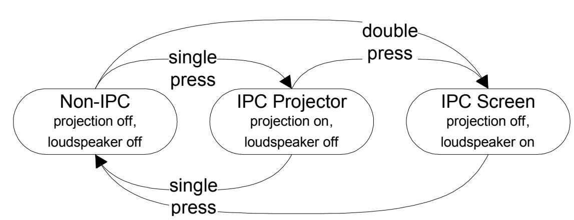


Figure 5: IPC modes, changed by different presses of the phone's projection button.

is held in front of the user, we considered whether we wanted to use the very same desktop UI on the much smaller phone screen or develop an alternative UI that resembles more the UI of standard phone software. Since we did not want to have completely different UIs for the same application to not overstrain users, we only slightly adapted the projected version to the mobile screen. Due to the smaller space on the mobile screen, we decided that private and shared spaces are exclusively visible, only. The user can move between spaces manually by performing a horizontal swipe gesture on the screen or automatically by dragging objects between space borders. Since views are separate, the mobile version does not allow resizing spaces.

IPC size configurations
As mentioned earlier, our goal is to support seamless switching between *IPC Projection* and *IPC Screen* mode. When a user switches from *Projector* to *Screen* mode, the sizes of his private and shared spaces shrink considerably. If the other calling party is in projected mode, the shared space sizes that are synced 1:1 are not equal any more. To account for that, the space available on the mobile screen is highlighted on the shared space of the user in *Projector* mode and remaining space is greyed out.

Group sharing and collaboration
During the design phase of IPC we took care to limit our concepts not to a two-person setup, but find solutions that would scale to conference calls with multiple users. The presented concepts, in particular the shared space with iconic representations of all participating users, color coding, lock, and pencil work equally well for a conference call with multiple participants.

IPC Use Cases
Calendar
The calendar application allows dragging the own calendar to the shared space and stacking calendars of different persons on top of each other to merge them and see all appointments together with corresponding color coding for each day and appointment. If new appointments are added in shared space, they are added automatically as shared events for all call participants that own the merged calendar, i.e. all persons that dragged their private calendar on top of the shared instance before. The calendar widget shows all information when being displayed in the private area but only information about free and occupied slots is visualized when shown in the public area. This helps to preserve private information. If needed all details could also be revealed in the shared space.

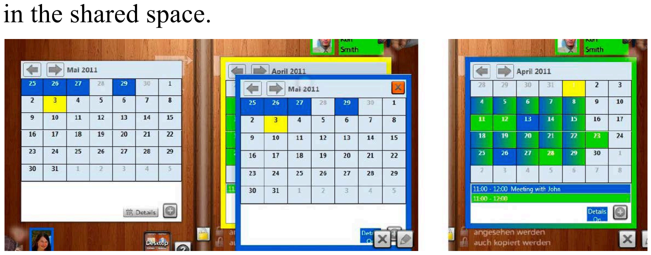


Figure 6: Merge calendars by stacking them.

Maps
Map windows include a Google Maps browser window, a search field and zoom and navigation controls. They can be used to bring a certain location into view and then share it, or to collaboratively explore the map in shared space. Annotations can be used to mark users current locations, as well as spots to meet, or park the car. This widget is in particular beneficial when discussing places to see or visit, when discussing routes or when planning a trip.

Pictures and Videos
Similar to the native phone gallery software, media files can be opened from a list of available gallery albums and their windows can be resized, rotated, or shared. This allows collaborative discussion of pictures and videos which we envision as one of the central usages of IPC.

Presentations
Sharing a presentation can be used to discuss revisions before the actual presentation is conducted. Furthermore, if the intended audience is not co-located, the presentation can be moved to and conducted in the shared space during a conference call. The IPC software supports sharing presentations, moving between slides in the shared space and annotations by means of the pencil.

Live Camera Image
A live stream from the camera capturing the area in front of the user can be shared if the mobile phone's camera is located on the same side as the projector. Anything in the view of the user that is relevant to the conversation, such as hand gestures, a sight of a beautiful landscape, items of interest while shopping or pictures on traditional paper, can easily be brought into the collaboration session.

PROTOTYPE
In the following we present our system setup, which we designed to fit the targets of the subsequent user study. To briefly summarize these targets, we wanted participants to engage in a real phone call while performing some collaboration tasks on the projected and the screen interface.

We had to develop a "projectorphone" prototype that projects a rectangular surface in front of the user whilst held at the ear; a system that tracks the user's fingers and maps it to the projected surface, independent from the surface's position; the IPC software with its underlying concepts and support for some content types (pictures, calendars, maps, presentations); and finally integrate aforementioned with the projectorphone to achieve the *IPC Projection* and *IPC Screen* modes. Moreover, we had to double the system and connect both systems to achieve a realistic call scenario between two persons.

The resulting overall system setup for the Interactive Phone Call is depicted in Figure 7. For reasons described later, the IPC software runs on computers that are via LAN connected to each other, the system that manages finger tracking, and additionally to respective projectorphones via VNC. The audio connection between calling parties is over standard cellular line from one phone to the other.

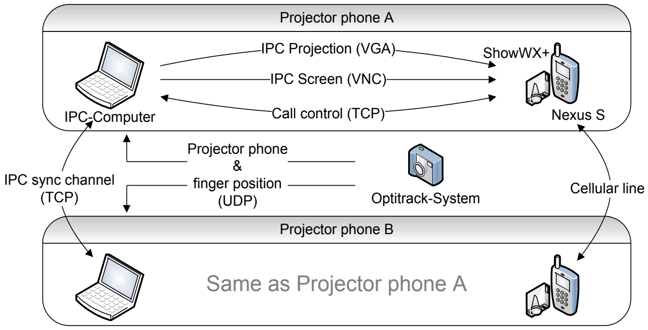


Figure 7: System setup. Two synchronized PCs running the IPC software receive input events from the tracking system and deliver their output via VGA to phone projectors and via VNC to phone screens.

Projector Phone Prototype

Because no suitable projector phone was on sale, we built a projector phone prototype that consists of a Samsung Nexus S Android phone attached to a Microvision SHOWWX+ laser pico-projector Figure 8. In order that our projector phone can be held as usual, i.e. to the ear and parallel to the face, we had to attach the devices orthogonally, since we wanted the projector to project a landscape image in front of the user. Additionally we attached retro reflective markers to the projector, in order to track it with the 6DOF infrared-based tracking system OptiTrack from NaturalPoint. The usage of a laser projector further allows the user to change height and angle of the projection without the image loosing focus. At a typical distance of about 60cm between ear and center of the projection on the table, the SHOWWX+, thanks to its wide projection angle, projects a bright 45x20cm-sized image with a resolution of 848x480 pixels. Because of the relatively short projection distance even small text (> 11pt) could be easily read. Another advantage of the projector-at-ear setup is that any jitter of the projection is almost unperceivable to the user since head and projector move simultaneously. In theory, jitter might become a problem while the user tries to touch the surface, but hardly was an issue in our tests and studies.

Obviously, phone and projector are only attached but not directly connected to each other. Nevertheless, because the phone is bidirectionally connected to a PC and the PC delivers its graphical output to the projector, we achieved the illusion that phone keys, in particular the on/off button on the side of the Nexus S, cycled through different IPC modes as desired. We also implemented anti-distortion of the projection and posture-independent finger tracking in order that users can independantly move, rotate, or change the height of the projector during a call to support their comfortableness. However, users are bound to the calibrated frame of the tracking system which does not let them stand up or move away from the table in front of them.

Anti-Distortion of Projection

We expect users of IPC to be more comfortable with a largely undistorted projection since they are likely more used to rectangular desktop interfaces. However, as [18] pointed out, it has still to be studied in which scenarios anti-distortion enriches the user experience notably.

Figure 8. The IPC hardware prototype. A SHOWWX+ Pico Projector is equipped with retro reflective markers and by two aluminum angles and velcro tape orthogonally and with height offset (for better handling and larger projection) attached to a Nexus S phone.

Projections follow the contrary perspective laws of the human eye: the farer the distance between projector and projection surface, the bigger the projected image gets. We can provide for an undistorted image on the projection surface by projecting a counter-distorted image. A counter-distorted image is the same image a 3D program would create to imitate the perspective view of the projected image from the position of the projector. We refer to [4,18] for the required computational steps to compute the projection matrix. The user's fingers are tracked in surface coordinates and mapped back to application coordinates by multiplying their position with the inverse projection matrix.

IPC Software

The IPC software (Figure 2) was built with C# and Microsoft's Windows Presentation (WPF) and Windows Touch frameworks, because current mobile phone UI frameworks are neither designed nor suited for table-top interaction and the much larger display space. The projected version is therefore served from a PC via VGA to our projector phone.

The *IPC Screen* version runs on Android OS and builds upon Android VNC Viewer to display and control the same IPC software via VNC, showing one space at a time as described earlier. The VNC connection introduces a small latency, but which is almost unperceivable from a user standpoint. Furthermore, the Android application runs a service in the background that communicates phone state (calling, ringing, off the hook) to the PC and receives control commands like "start call to x" or "end call with x" from the PC. The PC uses RealVNC for transmitting the Interactive Phone Call output to the mobile phone.

Our chosen setup has the advantage that it presents the user with the same user interface on the projection and the screen, while still retaining most affordances of the phone like hard buttons and the touch screen.

Real World Deployment Considerations

A real deployment of the system poses two major challenges. First, the rotation of the projector against the surface must be known to be able to project a counter distorted image. Second, finger touches must be recognized through some kind of optical tracking system that is onboard the projector phone. If the system further was to support unplanar projection surfaces as well, these must be detected through optical surface estimation as well.

Although there is no standard, ready-to-use method available, recent research and products showed how such a system could be realized. The orientation of the device can be sensed with the help of inertial sensors like accelerometers and gyroscopes already present on smartphones. This however would require an initial calibration step whenever the user changes the projection surface. If the phone featured a camera looking in the same direction of the projection, the camera could capture small visual markers in the corners of the projection to estimate spatial relation and distance between projector and surface without calibration. Sugimoto et al. showed how this could even be extended to support un-planar surfaces [16]. Once the spatial relation is known, finger tracking could be realized through shadow tracking like presented by Wilson [19]. Apart from that, very much like 3D cameras and 3D displays already found their way into mobile phones, we expect depth camera systems like Microsoft's Kinect to be introduced to projector phones in the future. Such a system delivering depth information would largely simplify the computation of the projection surface as well as the finger tracking even on un-planar surfaces and without disturbing the user visually or with calibration procedures.

In regard to the real-time synchronization, recent advance in mobile data networks, including today's support for video sharing, makes us confident that the realization of IPC's shared space is feasible today or at least in the near future.

PRELIMINARY EVALUATION

We conducted a preliminary evaluation to receive user feedback on the IPC system. Further we wanted to analyze and distinguish (a) the effect of projecting the interface during the call instead of using the mobile screen and (b) the extend to which the IPC concepts enhance in-call collaboration compared to standard phone software. For the sake of (a) we treated the *IPC Projection* (C1) and *IPC Screen* (C2) modes as two separate study configurations, which only differ in using the projection or screen. For the sake of (b) we introduced another mobile in-call collaboration system, the *Screen Sharing* system, as third study configuration (C3).

Screen Sharing Prototype

Configuration 3 (Screen Sharing) adds support for screen sharing and remote pointing to standard smartphones. The software consists of a small widget of four buttons (Figure 9). With the lower buttons (3 and 4) the user can control screen sharing. At the same time they serve as indicator for the current state. (a) shows the initial state where the user has not shared his own space (left icon) and neither has the other call participant (right icon). With a long press on (3) the user can allow (or prohibit) sharing her own screen. (b) shows the state after both participants allowed screen sharing. The user can invite the other participant to start watching her screen with a normal press on button (3). This may result in state (c), which indicates to the user that the other participant is currently watching her screen. By pressing (4) while the other participant allows sharing, the user starts watching the other participant's screen (d). Pressing (4) in (d) stops watching again. Moreover, (4) can be pressed in (c) or (3) in (d) to directly switch between watching jointly the own or the other's screen. With (1) the whole widget can be moved to the next screen corner to give free sight on the area below. With the pointer hand (2) both users can bidirectionally visualize their screen touches with separate colors to each other while viewing the same screen.

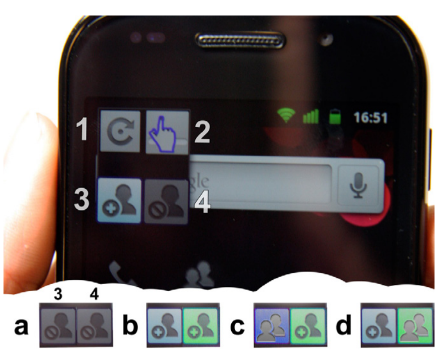


Figure 9: The Screen Sharing widget.

We added support for screen sharing and pointing to build a system that only uses standard phone software and at the same time allows solving the tasks of the user study. Content can be shared view-only through screen sharing and annotated by means of the pointing hand. Content can further be "copied" by e-mail or MMS.

Study Participants and Setup

For our user study we recruited 14 students (6 female, age 20-25) who all were experienced smartphone users. Participants were explained all configurations at the beginning and participants could explore the three configurations on their own.

During the study one experimenter stayed with the participant to give instructions on the tasks to perform and to assist if a participant would get stuck in solving a task. Another experimenter in another room played a close friend of the participant and engaged with participants in a real conversation over the phone. We chose this setup to mimic a real scenario while at the same time assuring that all conversations and actions took almost the same course. We employed a within-subjects design to compare *IPC Projection*, *IPC Screen*, and *Screen Sharing*. The order in that participants were exposed to the configurations was counterbalanced; the order of the tasks was always the same. Moreover, both experimenters followed a detailed script to synchronize their interaction and to ensure that all interaction with participants was very similar across all study sessions.

After each configuration we asked participants 12 questions, which could be answered from "strong disagree" to "strong agree" (5-point Likert scale). We also asked about perceived advantages and disadvantages of the system. After finishing the third configuration and questionnaire we asked participants to compare and rate the configurations in terms of performance and personal liking and tell us when, where, and why they would use such systems. One study session lasted approximately 80 minutes.

Study Procedure

Participants had to fulfill a series of tasks with each configuration. The first was to call the experimenter and to establish the collaboration with the means provided by the present configuration. Similarly, the last task was to end the call. In between, users had to perform the following four tasks:

(1) Open the gallery application, select and share own pictures and copy pictures from the other party. One own picture was considered private and therefore the participant had to ensure that the other calling party was not allowed to copy it.

(2) Recommend a place to meet for coffee to the other calling party, which pretended to not know the place. Here the user had to open the Maps application, look up the address by entering a search phrase, optionally pan and zoom, and then share the map centered on the destination. Further she annotated it (with the pencil) based on questions asked by the experimenter on the phone.

(3) Participants had to open the calendar application, merge their calendar in shared space with the calendar shared from the other party, and find a free slot for an appointment in the merged calendar. The other party added the appointment to the merged calendar and instructed the participant to check the appointment in her calendar in private space.

(4) Finally, the participant was requested to open and share a lecture presentation she had on her phone in order that the other party could look up a specific slide.

During the *Screen Sharing* configuration, pictures, maps, and presentations were presented through screen sharing. Pictures and presentations were exchanged via e-mail. Calendar entries were viewed separately with turn taking screen watching and the appointment was added by both calling parties separately.

RESULTS

Overall, participants gave us very positive feedback about all three systems. In regard to the question if and where they would use such systems they reported they would use them in almost every location and situation. In the case of *IPC Projection* we received some answers like "I would use it only in private areas, like at home or at work", but more feedback like "everywhere I am where I have a large projection surface" and "I would use it in public transport if space allows". One participant highlighted the fact that not projection *or* loudspeaker must be used, but that projection and loudspeaker can be used *together* for an easy to set up teleconferencing system between remote located groups.

Input and Output

In the final comparison of the configurations, 12 of 14 participants mentioned the bigger space as advantage of the projected interface and 5 that the phone can still be held at the ear. Further answers from the questionnaire are depicted in Figure 10. Unfortunately, the IPC configurations could not provide the very same input experience as the native Android applications in the *Screen Sharing* configuration (Figure 10, Q3). In *IPC Projection* this was due to the tracking system sometimes not recognizing a user's finger accurately for clicking or the click was recognized with a slight offset when the projector was tilted beyond a certain angle. No user complained about the projection jittering. In *IPC Screen* there was a small noticeable lag in interacting with objects due to constraints of the VNC connection. Responses to Q4 further show the desktop metaphor was the right decision for the projected interface but it does not perform so well when used on a mobile screen.

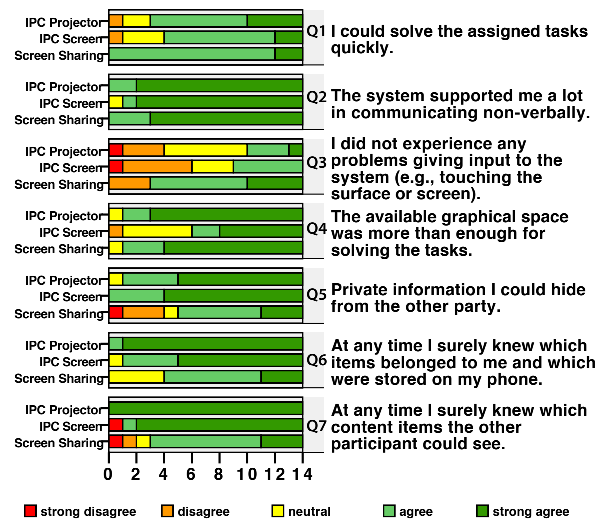


Figure 10: Selected questions/answers from the questionnaire participants filled in after each configuration.

Collaboration and Privacy

Answers to Q1 and Q2 indicate that the three configurations facilitated collaboration and that all tasks could be solved in a reasonable time. With more robust input in IPC configurations, we expect IPC approaches to perform at least as fast as *Screen Sharing*. One problem that participants had with the *IPC Screen* configuration was that because they could only see one space (private or shared) at a time, they sometimes missed an action the other participant performed in shared space.

The biggest difference however, we found in the perceived support of users' privacy. Answers to Q5, Q6, Q7 indicate that IPC configurations performed better in supporting the user's privacy. In the *Screen Sharing* configuration, users could only share their entire screen or nothing at all whereas the IPC configurations allowed a much more finegrained control. Because the given tasks required several switches between the own and the other calling party's screen, participants told us they were not always too sure whose content they were currently looking during *Screen Sharing*. Further they felt uneasy with the fact, that they could not be sure when exactly the other person started to watch their screen (again). Although the permission could be revoked at any time, users did not feel the same control as with the concept of private and shared space. Moreover, users did not know which content belonged to whom and which they had already shared (Q6).

Finally we asked users to rank the three tested configurations according to with which configuration they felt the fastest in solving the tasks and which configuration they preferred overall. The answers we got are interesting since although most users (6) felt the fastest with the Screen Sharing configuration (compared to 4 and 4), 11 participants in contrast favored one of the IPC configurations (6 *IPC Screen* and 5 *IPC Projection*), which we assume is for the aforementioned advantages of the IPC concept.

The positive user feedback we received for *all* three configurations shows that we compared three equally sophisticated systems with similar functionalities but opposite qualities. The results further indicate that the IPC improves in-call remote collaboration in a variety of use cases, even better than remote collaboration could be implemented on top of standard phone software. The evaluation also revealed that IPC concepts like the desktop interface and the private and shared space reveal their full potential only with the projected interface, which also has the advantages that it does not require activating the loudspeaker and may be used to integrate nearby persons in the call with help of the projection.

CONCLUSION

We presented the Interactive Phone Call and its concepts that facilitate synchronous collaboration during a phone call. Previous research proposed the use of additional hardware like PCs [7] while we explored the possibilities and requirements for a system that relies solely on mobile phones. Our presented system supports projectorphones as well as conventional phones through the *IPC Projection* and *IPC Screen* modes, which can be seamlessly switched to serve different mobile situations. We presented a preliminary evaluation of the IPC, also against another likewise novel system called *Screen Sharing.*

The results of our evaluation indicate that the IPC concepts, e.g., private and shared spaces, color coding, copy permissions, and the projected interface highly improve the user experience in synchronous remote collaboration in terms of visual communication and user control over sharing and privacy. According to study participants' positive feedback and their initial reports on their mobile phone usage and sharing habits, we are confident that the IPC could become an indispensible tool of mobile phone users. Our results inform future designers of synchronous remote collaboration systems from audio-visually connected touch-tables to mobile projected surfaces. In our future work we plan to investigate approaches that allow the usage of the IPC system outside of the laboratory and to conduct a comprehensive user study.

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REFERENCES

1. Ah Kun, L.M. and Marsden, G. Co-present photo sharing on mobile devices. *In Proc. of Mobile HCI'07*, ACM (2007), 277–284.
2. Ahern, S., Eckles, D. et al. Over-exposed?: privacy patterns and considerations in online and mobile photo sharing. *In proc. of CHI'07*, ACM (2007), 357–366.
3. Barkhuus, L., Brown, B., Bell, M., Sherwood, S., Hall, M., and Chalmers, M. From awareness to repartee: sharing location within social groups. *In proc. of CHI'08*, ACM (2008), 497–506.
4. Beardsley, P., van Baar, J., Raskar, R., and Forlines, C. Interaction using a handheld projector. *Computer Graphics and Applications, IEEE 25*, 1 (2005), 39-43.
5. Chapanis, A., Ochsman, R., Parrish, R., and Weeks, G. Studies in Interactive Communication: I. The Effects of Four Communication Modes on the Behavior of Teams During Cooperative Problem-Solving. *Human Factors: The Journal of the Human Factors and Ergonomics Society 14*, 6 (1972), 497-505.
6. Garriss, S., Cáceres, R., Berger, S., Sailer, R., van Doorn, L., and Zhang, X. Trustworthy and personalized computing on public kiosks. *In proc. of Mobisys'08*, ACM (2008), 199–210.
7. Gunaratne, J.A. and Bernheim Brush, A.J. Newport: enabling sharing during mobile calls. *In proc. of CHI'10*, ACM (2010), 343–352.
8. Harrison, C., Tan, D., and Morris, D. Skinput: appropriating the body as an input surface. *In proc. of CHI'10*, ACM (2010), 453–462.
9. Karitsuka, T. and Sato, K. A wearable mixed reality with an on-board projector. *In proc. ISMAR'03*, 321-322.
10. McFarlane, D.C. and Wilder, S.M. Interactive dirt. *In proc. of Ubicomp'09*, (2009), 205.
11. Mistry, P., Maes, P., and Chang, L. WUW - wear Ur world. *Ext. Abstracts CHI'09*, ACM Press, 4111-4116.
12. Myers, B.A. Using handhelds for wireless remote control of PCs and appliances. *Interacting with Computers 17*, 3 (2005), 251-264.
13. Raskar, R. and Beardsley, P. A self-correcting projector. *2*, (2001), II-504- II-508 vol.2.
14. Rukzio, E., Holleis, P., and Gellersen, H. Personal Projectors for Pervasive Computing. *IEEE Pervasive Computing*, 2011.
15. Sarvas, R., Oulasvirta, A., and Jacucci, G. Building social discourse around mobile photos: a systemic perspective. *In proc. of Mobile HCI'05*, ACM (2005), 31–38.
16. Sugimoto, M. et al. An Adaptive Projection Technique for Monochromatic Non-flat Surfaces using a Handheld Projector–Camera System. *In MP^2 Workshop CHI'11*
17. Tamaki, E., Miyaki, T., and Rekimoto, J. Brainy hand. *Ext. Abstracts CHI'09*, (2009), 4255.
18. Willis, K.D.D., Poupyrev, I., and Shiratori, T. Motionbeam: a metaphor for character interaction with handheld projectors. *In proc. of CHI'11*, ACM (2011), 1031–1040.
19. Wilson, A.D. PlayAnywhere: a compact interactive tabletop projection-vision system. *In proc. of UIST'05*, (2005), 83–92.
20. Wiltse, H. and Nichols, J. PlayByPlay: collaborative web browsing for desktop and mobile devices. *In proc. of CHI'09*, ACM (2009), 1781–1790.
21. Thrutu | Changing the Conversation. http://thrutu.com/.