Ask an Expert: Mobile Workspaces for Collaborative Troubleshooting

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Abstract

A key driver of enterprise adoption of consumer mobile devices is their potential to support collaboration. However, today there is little understanding of how well mobile devices support collaborative work activities in the enterprise. We present Ask an Expert, a tablet-based collaboration application for mobile industrial workers. Ask an Expert combines communication channels and content sharing tools in persistent 'spaces' to support collaborative troubleshooting between remote workers. We describe the user-centered design of Ask an Expert and provide design recommendations for mobile collaboration applications. We also discuss findings from preliminary user evaluations.

1. Introduction

Given the popularity of smartphones and tablets in the consumer space [9, 14], enterprises are rapidly adopting mobile devices for work purposes. Smartphones, tablets, and wearable devices have great potential to enable mobile collaboration for enterprise workers, especially in industrial settings. For instance, engineering and manufacturing companies with global operations face huge expenses due to equipment maintenance delays or production line issues. A key cause of such delays is that equipment and field maintenance crews are often located remotely from design experts who can provide troubleshooting help. Troubleshooting problems through asynchronous tools, such as emails and photos, adds costly delays that can be avoided with real-time mobile collaboration tools.

Designing compelling user experiences that bring desktop-based collaboration to mobile devices is challenging. Moreover, most mobile collaboration apps today are designed for consumers, and support light-weight collaboration tasks, such as photo sharing or instant-messaging. Few apps support multi-modal and longitudinal collaborative troubleshooting for engineering problems. Thus, we address the following research question – "How can we design a mobile app that supports collaborative troubleshooting between field technicians and remote experts?"

Following a user-centered design methodology, we first conducted contextual inquiry at a power plant to understand the collaboration challenges of mobile industrial workers. Next, we designed a high-fidelity prototype application to evaluate the utility of various collaboration technologies in addressing the challenges observed in the field. Based on evaluation results, we developed seven design goals and re-designed our prototype into a workspaces-based application, called *Ask an Expert*, which supports multi-party, multi-modal collaborative troubleshooting. Finally, we conducted preliminary evaluations of *Ask an Expert*.

Our study makes two important contributions. First, we provide design recommendations for a mobile collaboration app based on field research and iterative prototyping. Second, we describe the design of *Ask an Expert* and findings from preliminary evaluations, highlighting important design considerations for enterprise mobile collaboration apps.

In the following sections, we first present our findings from contextual inquiry and evaluations of the early prototype app. Next, we describe how we drew on those findings and relevant literature to re-design the app. Finally, we describe the outcome of our evaluation of *Ask an Expert*.

2. Contextual inquiry

There is little understanding of how mobile workers collaborate on troubleshooting activities. To understand the collaboration challenges of mobile workers, we studied field engineers at a large industrial company, Unicom (pseudonym). Unicom has a global energy business that specializes in power generation, distribution, and management. Unicom's field engineers install and maintain power plant equipment for customers. The site for contextual inquiry was an 1800MW natural-gas power plant in the South-eastern United States that had been shut down for planned maintenance activities (*i.e*, an "outage"). Over two days, we conducted 18 hours of observation and interviews on site with three field engineers (all male, 28–47 years old). Next, we highlight the key findings from contextual inquiry.

2.1. Work activities of field engineers

Unicom's cogeneration power plants typically contain gas turbines, steam turbines, and generators. During the outage, field engineers disassemble power plant equipment, inspect them for issues, and reassemble them. When difficult issues arise, field engineers file a "case" using a Web-based ticketing tool to get help from remote product engineering experts. Experts review cases and advise on corrective actions, which are then performed and documented. Finally, field engineers prepare reports, invoices, and other documentation for the customer.

The majority of the work of field engineers is manual and mobile. Trailers at the job site serve as offices. These trailers contain laptops, portable printers, paper documents, and physical tools. Most engineers do not have enterprise-issued mobile devices and use their laptops to communicate with peers and complete online workflows. Internet access at most field sites is available through 3G/4G cellular networks. Field engineers often carry mobile hotspots (e.g. MiFi devices) as they walk around a job site.

2.2. Collaborative troubleshooting

We observed multiple instances where field engineers needed troubleshooting help in the field. The following is an example of such a scenario –

"*The turbine combustion shell has visible cracks. The field engineer looks at paper drawings of the turbine sections and annotates them to show the crack positions. He scans and emails the annotated drawing to experts to get advice on how to disposition the cracked sections.*" – field data

Though the formal process of getting help on such a problem is through the online case-filing tool, participants mentioned that they often informally reach out to experienced field engineers or known experts via phone calls. This is because the asynchronous nature of the formal workflow does not support real-time discussion and feedback, leading to delays.

Describing problems to experts is a kind of "storytelling", where artefacts from machines, from colleagues, and from enterprise databases are assimilated and presented to best facilitate the problem solving processes of experts. In the absence of specialized tools, participants reported using separate tools such as email, phones, and screen-sharing applications on laptops. This led to a fragmented collaboration experience where collaboration artefacts were distributed across these tools.

2.3. Need for mobile collaboration tools

Participants expressed the need for synchronous mobile collaboration tools to share problem context in real-time. For instance, video-calling from a mobile device would be useful for showing a remote expert the specifics of the problem. Similarly, synchronous, multi-party annotation of photos would enable in-situ collaborative troubleshooting. Also, quickly finding and sharing task-related knowledge stored on enterprise drives and websites would be important. Finally, leveraging social networks for sharing 'tribal knowledge' was deemed important but is not explicitly supported by available collaboration tools.

Regarding form factor, participants felt that phones were easy to carry and use, especially when crawling into small spaces and carrying other work tools. On the other hand, they felt that tablets would be better for mobile information consumption and data entry.

3. Evaluating a prototype app

Based on the findings above, we designed a prototype app to evaluate collaboration technology on an iPad and to get feedback from mobile workers about the utility of such technology. We chose the tablet form factor to support media-rich collaborations and information consumption. The key features were –

- An expert directory (i.e., contact list) with presence status of each contact
- Peer-to-peer video-calling and instant messaging
- Real-time collaborative annotation of images
- Screen-sharing of documents
- Geo-location of remote experts on a map

These features were arranged in four tabs – Directory, Pictures, Documents, and Maps (Figure 1).

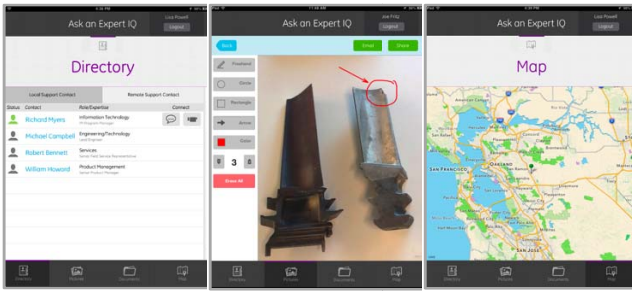

Figure 1. Screenshots of the prototype app.

3.1. Evaluations of the prototype

We evaluated the prototype app via two studies – a controlled study and a field trial.

3.1.2. Controlled study

We conducted a controlled study at Unicom's Learning Center where field engineers receive job training. Eight field engineers (75% male, 24–57 years old) participated in this study and were randomly selected from a training class. We collected feedback using scenario-based tasks with think-aloud protocol, a survey, and a focus group.

Evaluation results suggested that such an app would be useful for field engineers in expected ways. One participant noted – *"Being able to contact ... engineering with questions w/o having to go back to office to chat from laptop would save time and be very helpful."* – Generator specialist 1.

We elicited detailed feedback about usefulness, satisfaction, and ease of use of the app and individual features through a survey based on USE [17]. The survey contained questions about usefulness, satisfaction, and ease of use of the app and individual features. Answers were on a 5-point Likert scale (1 = strongly agree, 5 = strongly disagree) and were received from eight field engineers (Table 1).

Table 1: USE survey results

	Usefulness	Ease of use
Video call	2.25	2.00
Instant messaging	1.75	1.71
Image sharing	1.38	1.88
Document sharing	1.75	2.14

While contextual inquiry participants had strongly expressed a need for video-calling, app evaluators were concerned about the usefulness of video-calling given poor cellular network connectivity. As one participant described – "*The connectivity took away the full value of the [video call] tool. Even with 4G signal, the other tablet could not hear me well*" – Field engineer 3.

Also, participants did not feel the need to see each other on the video call. They felt that while video-calling would be used to share problem context, it would not be necessary for simpler cases. Given low performance of video-calling in bandwidth constrained conditions, participants found sharing pictures along with instant messages adequate for their needs. As one participant noted – "*As long as I have the capability to share images in regular chat, I see no advantage of video chat as the video quality is poor and in most remote sites it would not work at all.*" – Generator specialist 2.

The ability to annotate and share images in real time was considered the most useful feature, while instant messaging was considering the easiest to use. Finally, the map feature showing the real-time location of contacts raised several privacy concerns. Participants felt that they were being "tracked". Also, they didn't feel the need to know the exact location of peers, although it might be useful to know if there were work crews at neighbouring job sites.

3.1.2. Field trial

We also conducted a field trial of the prototype at a power plant in the Southern US during an outage. During this field trial, three field engineers and a product services engineer (all male, 37–51 years old) used the app for three days during their work activities. We collected data through 45-minute informal, semi-structured interviews at the end of the trial. Since the trial site had poor cellular connectivity, we provided each participant with a mobile hotspot. We also ruggedized the iPads by providing industrial-strength cases for protection.

The field trial revealed several drawbacks in the overall interface design that limited the usefulness of the app in real situations. Separating content sharing and communication features into separate tabs led to a fragmented user experience. For instance, when users annotated a picture with a collaborator while communicating over a video call, they had to constantly switch between the Directory and Pictures tabs. Similarly, participants had little awareness of where collaborators' attention was focused at any given time. For instance, one collaborator could be annotating a picture while the other could be viewing a document. This led to coordination overhead where participants had to use the audio channel to coordinate attention. Thus, it was critical to combine collaboration and communication features into a user experience that would support collaborative problem-solving.

Lack of persistence of content was another challenge for users. Since collaboration sessions were not persistent, collaboration artifacts were lost once the session ended. This forced participants to initiate multiple collaboration sessions for the same problem.

Another important finding was that poor network connectivity at job sites impacted app performance. Thus intermittent connectivity would be an important design consideration. Overall, the findings supported our intuition that merely providing separate consumer apps for photo sharing, video calling, and document sharing would be inadequate for enterprise collaborative problem solving.

4. Design of *Ask an Expert*

We drew on the above findings and relevant literature to re-design the prototype app into a new app

called *Ask an Expert*. We first present related work and the design goals, followed by a description of the app.

4.1. Related work

4.1.1. Help-giving systems. Troubleshooting problems is a complex interaction between technicians and help-givers, and involves not only formal information sources, but also informal conversations and knowledge sharing. Ethnographic studies [4] of help-giving systems have found that practitioners' use of documents, tools, and conversations are intertwined as they find and use information relevant to their work. For instance, Orr [19] found that informal, everyday conversations and the telling of stories were crucial for knowledge sharing among service technicians. Similarly, Yamauchi et al. [22] found that while technicians follow company-documented procedures, the more common practice, is 'gleaning' informal tips from other technicians. The researchers developed Eureka, a laptop-based tool for service technicians to share their practical knowledge.

These studies, and our findings from contextual inquiry, highlight the importance of supporting help-seekers' informal practices of exchanging knowledge with experienced peers. Thus, *Ask an Expert* supports building and maintaining network of experts and peers.

4.1.2. Remote guidance tools. Several studies have indicated the value of remote assistance in field workers' troubleshooting of equipment. Crabtree et al. [4] found that when workers and remote experts troubleshoot together, a lot of effort goes into articulating the problem, situation, and instructions. They suggested using mobile phones to augment verbal communication through gestures and projections. Based on such studies, researchers have developed remote-guiding tools where a remote helper guides a worker performing a task requiring the manipulation of physical objects and devices. During such remote guidance, visual information has been found to play an important role in providing grounding between workers and helpers [7]. Hence, video-mediated communication has been studied in detail, including different video configurations, support for pointing and gestures [15], and augmented reality applications [8].

In such applications, views of the task object have been provided using head-mounted displays and other wearable devices. Few of these studies, however, have looked at the use of mobile-device cameras that allow both 'talking heads' views as well as views of the work object. TeleHealth [16] is one such system; it uses tablets to support communication between community health workers and remote clinicians. The tool allows video-conferencing, cloud-based information sharing, shared annotations and asynchronous rich media. *Ask an Expert* provides similar capabilities, but within persistent workspaces that combine content sharing and communication features.

Several remote guiding tools have focused on how help-givers can effectively point to remote objects. E.g. HandsOnVideo [1] captures hand gestures of helpers and projects them onto a near-eye display worn by the worker. Most of these remote guidance tools are either limited in terms of supporting the mobile aspects of the work or require wearable devices. However, we found that it is challenging for technicians to wear specialized devices in addition to required safety gear (such as, safety goggles and hard hats). Moreover, our goal was to utilize popular consumer mobile devices rather than to create specialized hardware. Finally, the scenarios we encountered were not limited to one-time guiding of tasks but included long-term discussions of technical information.

4.1.3. Mobile collaboration. CSCW researchers have conducted rich studies of tools to support distributed collaboration in the wild [18], highlighting the role of coupling, coordination, and awareness. However most of these studies have focused on desktop-based collaboration. Studies of mobile collaboration have typically supported *implicit* collaboration through location-awareness. For instance, GeoHealth [2] combines geographic location with home healthcare services to provide distributed healthcare workers with spatial awareness of co-workers and patients. Mobile G-Portal [21] connects PDAs for collaboration in geography fieldwork. One of the few systems for industrial workers is ABB Powerwall [6] that supports synchronous, co-present collaboration using mobile devices and large shared displays for information browsing, visualizations and annotations.

There are several mobile collaboration apps in the consumer space, such as Skype, Google Hangouts, Cisco WebEx, and Adobe Connect. These apps are designed to support peer-to-peer communications, social networking, and meeting management. Most of these apps allow light-weight collaboration and are inadequate for multi-media collaboration sessions for troubleshooting engineering problems. Others, such as meeting management apps, allow content sharing but require prior scheduling of collaboration sessions. Hence, they are ill-suited for the ad-hoc collaboration scenarios we observed in the field. *Ask an Expert* supports both light-weight and media-rich, ad-hoc collaborations. A similar app for industrial troubleshooting is the Librestream Onsight (http://www.librestream.com) app. It offers video,

voice, and onscreen drawing but requires the use of custom hardware.

4.1.4. Mobile workspaces. Tools that support distributed collaboration often provide virtual workspaces that mimic real ones [10]. While CSCW researchers have studied desktop workspaces heavily, such workspaces are limited in terms of supporting mobile users [5]. Since mobile users need to connect and disconnect periodically, mobile workspaces have special design considerations [11]. However, there is little prior work in the HCI literature on how to design effective mobile workspaces, especially for problem solving tasks. An important aspect of the design of workspaces is supporting awareness [10], so participants can coordinate action, talk about the task, and assist each other. Due to the limited real estate of mobile devices, it is especially challenging to design for workspace awareness.

Ask an Expert tackles the challenge of designing effective mobile workspaces by supporting asynchronous and offline collaboration modes, persistent artifacts, and workspace awareness.

4.2. Design goals

DG1. Support both short-term, peer-to-peer collaboration and longitudinal, multiparty collaboration. We observed that mobile troubleshooting occurred in two predominant modes in the field. One was short-term, peer-to-peer collaboration in which help-seekers wanted to make a quick call or exchange a short message with an expert. Such collaboration typically lasted for a few minutes and did not involve simultaneous content sharing. The other was longitudinal, multi-party collaboration, which often started with a light-weight, peer-to-peer exchange but evolved into multi-party collaboration with content sharing. Such collaboration lasted over days, with the shared content needing to persist. Furthermore, collaborators often didn't know *a priori* which style of collaboration a given problem would call for.

Thus, it is important to not only support both kinds of collaboration, but also to support seamless transitions between them. Also, persisting content in a problem solving session is critical.

DG2. Support both loosely and tightly-coupled collaboration. Level of coupling, i.e. how closely coordinated and inter-dependent group members are, is an important design dimension for mobile collaboration. In 'tight mobility', mobile collaborators are synchronized in real-time, while in 'loose mobility', collaborators independently access artifacts and share information while still cooperating [3]. We found that mobile problem solvers often need to collaborate in tightly coupled ways. However, intermittent network connectivity often called for loosely-coupled modes. Also, given the highly technical nature of problems, experts often need to intensively examine the evidence and related knowledge while help-seekers continued working in a loosely-coupled way.

DG3. Support both online and offline modes of collaboration. Due to intermittent connectivity, collaborators needed the ability to work in an offline mode (e.g., for collecting information related to a problem) and save their work for sharing when connectivity was available. Hence, it is important to support both online and offline modes of operation, as well as seamless transitions between these modes.

DG4. Support awareness. During evaluations of the prototype, we found that one of the key challenges for users was lack of awareness. Field research suggested that it would be especially critical to provide the following kinds of awareness – who is part of the collaboration, who is sharing the objects that participants should focus on, what is currently happening, and where is each participant currently working? Finally, since mobile workers disconnect periodically, collaborators need dynamic awareness of online/offline status of collaborators.

DG5. Support integrated communication and content sharing. Communication and content-sharing features were separated into tabs in our prototype, leading to a fragmented user experience. When solving a complex problem, communication tools like video and chat were used in conjunction with content sharing; hence it is important to integrate these features. Also, it is important to allow users to easily switch focus between communication channels and shared content like pictures and documents.

DG6. Support building expert networks. Participants in our field study mentioned that engaging the right expert for the given problem was critical for timely issue resolution. Thus, it would be important to enable users to find and invite experts to collaboration sessions. Algorithmic ways of recommending experts was beyond the current scope of our work. However, our research suggested that it would be useful to allow users to self-describe their expertise so potential collaborators could use that information for building their network of contacts.

DG7. Support importing and exporting content. In an enterprise, information related to solving problems is often captured and stored in an ecosystem of devices and online tools. Thus, easy integration of artifacts from external sources (such as, a camera or a website) into collaboration sessions would be critical for collaborators. Also, being able to export collaboration artifacts from the app to other workflows would be useful.

Next we describe the design and functionality of *Ask an Expert* based on these design goals.

4.3. Layout and functionality

Ask an Expert combines communication tools with content sharing features in persistent 'spaces'. It employs a client-server architecture where the server stores spaces as collaboration sessions and provides back-end services for communication and collaboration features. It has four screens – Contacts, Spaces, Profile, and Notifications.

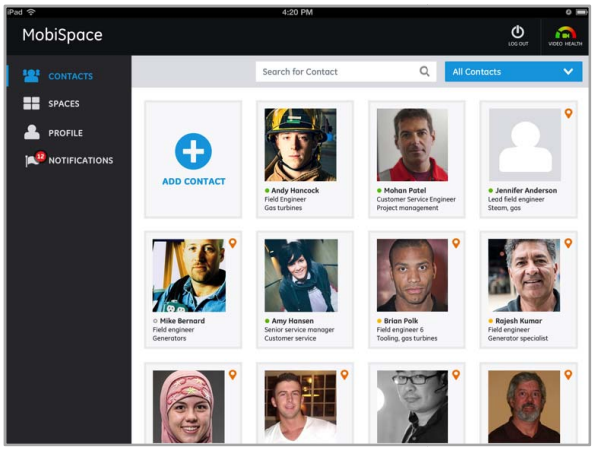

Figure 2: Contact screen

4.3.1. Contacts. The Contacts screen (Figure 2) is the landing screen when the user logs into the app. This screen lists all contacts, with the following information displayed for each contact – name, role, expertise (user-defined keywords), and physical proximity (indicated by a 'pin' icon if a contact is within 100 miles). Users can organize contacts into groups based on task, site, or other criteria.

Based on **DG6**, the Contacts screen allows users to build and manage their personal networks. Users can search the database of all app users by name, role, and expertise, and add selected contacts to the app. Selecting a contact provides the option to "Start a Space" with that contact. A space can also be started from the Spaces screen (Figure 3) without specifying collaborators, and collaborators can be added as the task progresses (**DG1**).

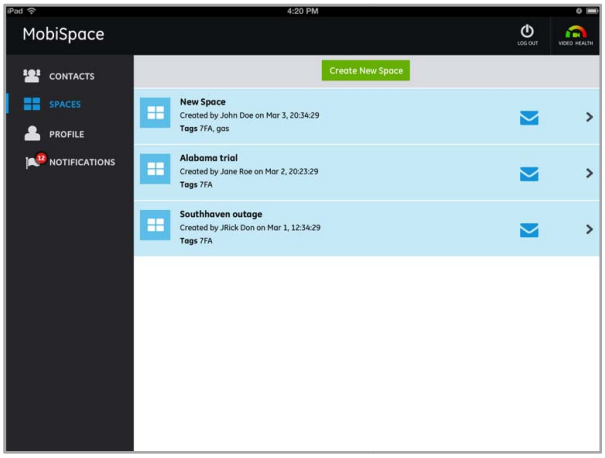

Figure 3: Spaces screen

Thus, spaces support smooth transitions between peer-to-peer and multi-party collaboration (**DG1**) as well as individual modes of working when users are offline or want to work in a loosely-coupled way.

4.3.2. Spaces. The central design concept in *Ask an Expert* is a space. A space is a metaphor for a workspace where multiple collaborators can annotate and share content while communicating using video, instant messaging, and screen sharing. A space has the following key sections (Figure 4, next page) –

1. Communication Tools: The top left section of a space contains audio, video, chat, and screen sharing tools. An audio channel is associated with each space. A chat room is also associated with a space and allows all participants to exchange chat messages. There is a single video channel associated with a space, so participants can broadcast their video. The rationale for single-channel video came from the finding that video would be used infrequently, with image-sharing and chat being a good substitute for video. Also multi-party simultaneous video, would be hard to support in bandwidth-constrained conditions. Collaborators can also share their screen.

Floor control is left to social convention and can be discussed by collaborators over audio or chat.

2. Annotation toolbar: The annotation toolbar is contextually available when a user is viewing content (i.e. a document or a picture) in the Canvas. It contains standard annotation tools such as freehand drawing, drawing of shapes, color selection, undo, redo, and erase. Annotated documents and photos are automatically saved in the Content Bar of a space.

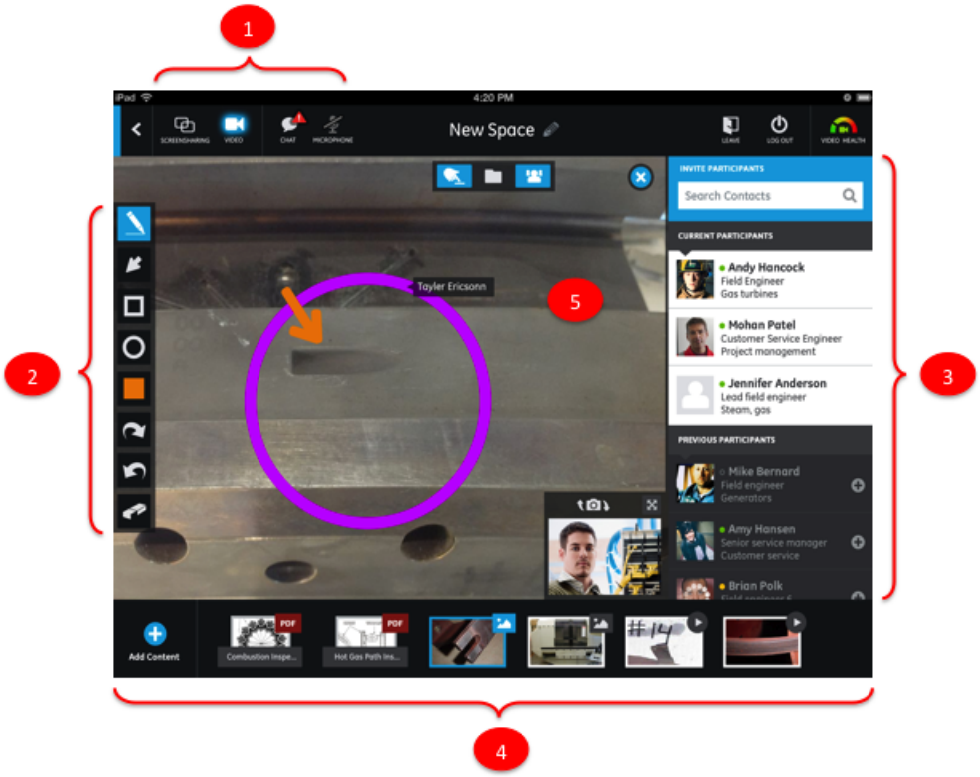

Figure 4: A space contains – (1) Communication tools, (2) Annotation toolbar, (3) Participant bar, (4) Content Bar, and (5) the Canvas

3. Participant bar: The participant bar has three sections – "Current Participants" lists those collaborators who are currently viewing the space, "Previous Participants" lists any users who have previously participated in that space, and the "Invite Participants" search field allows participants to invite additional collaborators. The search field allows searching for contacts by name, role, or expertise keywords. Collaborators can also invite a past participant to re-join the space. As participants join and leave a space, they appear in the current and previous participants lists accordingly.

4. Content bar: At the bottom of the space is the Content bar, which allows collaborators to add and share content related to the problem resolution task. Three kinds of content can be added to a space – documents (pdf format), photos, and videos. Content can be added from external sources, such as the browser, the tablet camera application, and the photo gallery.

5. Canvas: The Canvas is the area of the space that is shared during screen-sharing. Content can be dragged and dropped into this area from the Content bar for sharing. While sharing content, users can use video or audio channels to communicate with collaborators.

Based on **DG5**, a space combines communication tools with content sharing in a single screen. To accommodate multiple features on limited tablet real estate, *Ask an Expert* employs mobile interaction design patterns such as infinite lists with scrolling, popovers, slideouts, and carousels [12]. In accordance with **DG4**, spaces provide rich mechanisms for supporting awareness. Awareness about the presence and identity of collaborators is provided through the Participant Bar. Embodiment proximity techniques [10], such as video and screen-sharing icons in the Current Participant list, indicate who is sharing. Color-coded annotations provide authorship awareness. Having a single area for content sharing, (i.e., the Canvas) allows easy coordination of gaze and view focus. Similarly, having a single area for shared content (i.e., Content Bar) with equal access rights for all collaborators provides 'reach awareness' [10].

Based on **DG3**, spaces support both online and offline use. When users visit past spaces in offline mode, they view the last-synced view of the space. They cannot view participant information or access real-time communication tools. However, they can add content to a space and annotate it. Any changes made to a space when offline are sync-ed when the user is online again.

Based on **DG2**, spaces support tightly coupled collaboration by providing real-time communication

tools like video and screen-sharing. Offline mode supports loosely coupled collaboration. Users can also work in an "individual mode" where they add and view content, and navigate to other parts of the app, while another collaborator is sharing. Spaces, once created, persist 'forever' (**DG1**). The Spaces screen (Figure 3) allows users to access their spaces, create new spaces, rename spaces, and tag them.

4.3.3. Profile. The Profile screen allows a user to enter and edit profile information. Profile information can also be provisioned from enterprise employee databases. Users can enter keywords in their profile to describe their expertise (**DR6).**

4.3.4. Notifications. Notifications enhance user's awareness about others actions (**DG4**). Notifications are generated when users are invited to join a space or are added to another users' Contacts. The Notifications screen logs all notifications and displays badges to indicate unread notifications.

4.3.5. Integration with external content and workflows. In accordance with **DG7**, *Ask an Expert* allows importing content into a space and exporting collaboration products to include in other workflows. When users are browsing a website or a document management app, they can pull a document into a space for sharing. For this, once they click on the document in the external app (e.g. Safari or Dropbox), they have an option to open the document with *Ask an Expert*. Selecting that option launches *Ask an Expert* and provides the user options to add the document to a new or existing space. The document appears in the Content Bar of the selected space. To export content from a space, users can email Content associated with a space by selecting the 'email' icon next to a space in the Spaces screen. They can select multiple pieces of content from a space and contacts to send those to.

5. Evaluation of MobiSpace

We conducted user evaluations of *Ask an Expert* to answer the following questions – 1) Would users find *Ask an Expert* design concepts easy to understand and useful? and 2) How can the design of *Ask an Expert* be improved?

5.1. Methods

We first evaluated mockups of *Ask an Expert* with seven field engineers (our primary design persona) through remote sessions over the phone and a screen-sharing application. Participants (all male) were Unicom field engineers from the US, India, Middle East, and South Africa, with average work experience of five years. They were recruited from a global field engineering team participating in similar initiatives. We also included an experienced remote expert. We did not include additional remote experts as it was determined that they would use the app on the desktop instead of on mobile devices.

Participants were presented a storyboard (with mockups) of how they would use the app. We introduced the major app features and participants were free to ask questions. After the storyboard walkthrough, we asked a series of open-ended questions about the design.

In addition to evaluating *Ask an Expert* with field engineers, we conducted another study with other enterprise workers to examine whether the concepts were universally understandable and applicable. Six participants (25% male) participated in teams of two each. Participants were Unicom employees in software development roles and were recruited using internal mailing lists. We provided participants with iPads with the app, introduced them to the major features, and let them explore the app on their own for 20 minutes. Using think-aloud protocol and observations, we noted how they collaborated with their partners. At the end of the exploration, we asked participants open-ended questions about their experience.

5.2. Findings

We discuss findings from all participants together as we found similar themes regarding overall utility of the app, how participants understood the concept of spaces, and implications for providing informal modes of troubleshooting. We also discuss additional features suggested by participants to enhance *Ask an Expert*.

5.2.1. Overall utility. Field engineers validated that the app would be useful for seeking help during troubleshooting. Sharing real-time, contextual information about a problem and the ability to annotate in real-time were considered the most valuable features. Participants also liked the ability to search for and build a network of experts.

Most participants likened a space to familiar metaphors like a chat room (but with richer tools and content sharing) or a WebEx meeting (but with persistent content). They noted that while the concept of a space felt familiar, the additional functionality, as compared to status quo tools, made spaces a unique construct. Participants especially found the social aspect of spaces unique and wanted to leverage this aspect in new ways. For instance, they wanted to

search across spaces, or find related spaces to explore the problem-solving strategies of other groups.

5.2.4. Integrating formal and informal communications. Most enterprises have formal, documented processes for problem solving activities. In Unicom's case, the formal case resolution workflow through the online ticketing system ensures accountability to Unicom's customers, who are driven by documentation and measurability. Designated experts are measured on how many cases they close and how quickly they close them. Furthermore, field engineers are held accountable to taking the recommended actions. *Ask an Expert* provides an alternative, informal way to discuss problems through video calls and instant messages. Participants wanted the informal conversations and recommendations in spaces to be linked to the formal case resolution process. Though *Ask an Expert* allows exporting space contents to be included in other workflows, future work needs to address the true integration of *Ask an Expert* conversations with enterprise formal workflows.

The informality of contacting experts through *Ask an Expert* also prompted participants to wonder about expert availability. Given their limited number, designated experts could easily get overloaded with requests to join spaces. Participants suggested that we add features to balance the load for experts, such as queuing incoming space invites or indicating an expert's availability to participate in a space.

5.2.2. Collaborative sensemaking of space contents. Participants expressed concern about how they would make sense of space contents when a high volume of shared content has accumulated in the Content Bar. Sensemaking of space contents would be especially critical for asynchronous, longitudinal collaboration. Similar issues have surfaced in studies of collaborative Web search where various visualization techniques have been applied to enable sensemaking of content shared during collaborative search sessions [20]. However, further research is needed to examine whether such techniques can be extended to summarizing technical content, such as would be shared in *Ask an Expert*. Users' sensemaking of space contents could also be aided through crowd-sourced ratings and comments. For instance, if several documents and images pertaining to a problem have accumulated in the Content bar, collaborators can rate each one on its relevance to the task at hand.

5.2.3. Search and analytics across spaces. Participants wanted mechanisms to surface high-quality content across spaces and expressed the need for search functionality. They wanted to find related spaces and content by searching the spaces they had participated in, as well as the global pool of spaces. This raises questions about ownership and visibility of a space. Currently a space is uniformly visible and accessible to all participants, but not visible or accessible to other *Ask an Expert* users. In order to support search functionality, spaces might need finer-grained access control.

Participants wanted the app to automatically suggest relevant experts and documents for a space. Thus, it might be valuable to provide analytics-based recommendations that surface common problems, effective solutions, and successful experts.

5.2.5. Expert recommendation. Participants mentioned that they would need help in identifying experts to invite to a space since today they are assigned experts through the online ticketing system and don't have much knowledge about the expertise of designated experts. Though *Ask an Expert* supports self-described expertise, participants mentioned that keywords might be insufficient to describe specialized technical expertise. There has been much research [13, 23] on expert recommendation for consumers and knowledge workers whose online traces can be mined using automated techniques. The challenge for a tool like *Ask an Expert* is to recommend experts for physical tasks, an area that is understudied.

6. Limitations and future work

While we present preliminary user evaluations of *Ask an Expert*, an in-field evaluation is important for understanding the true utility of the app. App usage data can be logged and analyzed to provide insight into patterns of use. Such analysis will also help us understand how spaces are managed and how they might be integrated with other practices. Finally, we have not examined the effect of hardware durability, and environmental factors, (e.g., harsh weather, dust, and noise) which might impact *Ask an Expert* usage. Improving performance in low bandwidth conditions also requires further examination.

7. Conclusion

We provide design recommendations for mobile collaboration apps based on field research and iterative prototyping. We also describe the design of an app that provides mobile workspaces for collaborative troubleshooting. *Ask an Expert* makes workspaces, a long-studied CSCW concept, mobile and social.

Evaluations of *Ask an Expert* suggest that it supports media-rich, collaborative troubleshooting between remote users. Though our study focuses of industrial workers, it can inform the design of similar applications for enterprise knowledge workers.

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