Robit: An Extensible Auction-based Market Platform for Challenged Environments

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***Abstract*—Open and competitive marketplaces, like those enabled by the internet, bring enormous value to consumers while fostering innovation and growth across a wide variety of businesses. Electronic commerce has forever changed how people trade goods and services. Last year alone, US consumers spent more than $150 billion dollars on internet sales [5]. However, developing countries largely have not benefited from these advances, often due to low network penetration, lack of locally relevant markets, and requirements for additional facilities (such as credit cards, shipping arrangements etc.) to take advantage of such marketplaces. Even when these markets are established with local content and poor connectivity in mind, they are often specific to a certain domain or community. This paper introduces *Robit*, an extensible auction-based market platform for use in challenged network environments. Robit enables developers to incorporate a market layer in their applications and open their service to a wider audience. Robit is built with challenged environments in mind, where communication channels are narrow and potentially expensive. The market structure in Robit is based on a survey of studies in auction theory and economics, and incorporates widely available communication tools. To demonstrate how Robit can be used to add a market layer to digital services, we have modified an open source data fetching application targeted towards challenged environments to use our platform. In addition, we analyze a standalone auction-based marketplace constructed using the Robit infrastructure. We also describe an in-country user study and a small pilot deployment for proof-of-concept.**

I. INTRODUCTION

Developing countries face significant challenges in network access. Bandwidth is the cornerstone of today's global knowledge economy, but it is scarcest where it is most needed—in the developing regions of the world which require low-cost communications to accelerate their socioeconomic development [20]. The available end user bandwidth in these countries is orders of magnitude less than that of the developed world, and costs significantly more. For example, a 2Mbps connection in Ethiopia, provided by The Ethiopian Telecommunication Corporation—the only legal provider in the county—costs nearly $4500 a month [11]. On the other hand, a 15 Mbps fiber optic connection in the US costs less than $50 per month [38]. Consequently, even some of the most well-endowed education and research centers in these countries have less bandwidth than a home broadband user in North America or Europe, and it must be shared amongst hundreds or even thousands of users [20]. Most connectivity is provided through dial-up services, often found in internet kiosks or public libraries. These are also shared among multiple users at a time, and have delivered bandwidth to a user often less than 15Kbps [27]. This makes even simple network tasks unpleasant and rich media prohibitively difficult.

On the other hand, a number of experiences in the developed and developing world have shown the enormous value open marketplaces, as those enabled by the internet, bring to the community [8], [10], [16]. Electronic commerce has forever changed how people buy and trade goods and services, fostering competition and growth across a wide variety of businesses. However, developing countries largely have not benefited from these advances, often due to low network penetration, the lack of locally relevant markets even for those who have some access, and requirements for additional facilities (such as credit cards, shipping arrangements etc.) to take advantage of marketplaces. Even when these markets are established with local content and poor network resources in mind, they are usually specific to a certain domain or community [13], [25], [34], [35].

In this paper, we introduce *Robit*, an extensible auction-based market platform for operation in challenged environments. Robit enables developers to incorporate a market layer in their application, and open their service to a wider audience. Providers and consumers will benefit from the greater number of transaction options and product information brought by the added market structure, resulting in a *social surplus* increase [21], [33], [37]. Robit develops from experiences of building market oriented digital services for challenged network environments, and a survey of auction based marketplaces. The market platform uses a customizable auction mechanism based on a modified second-price auction structure. Robit is targeted towards challenged network environments, where communication channels are narrow and potentially expensive.

The user-facing communication channels in Robit are SMS and voicemail, leveraging the wide penetration of cellular telephones in developing counties. By the end of 2008, there were more than 4 billion mobile telephone subscribers around the world, with Africa having the highest mobile growth rate [19]. In Ethiopia, for example, there are about twenty five times as many mobile subscribers compared to internet subscribers [12]. This allows us to take advantage of widely available services like SMS in our design. In addition, voice based solutions, such as VioKiosks [1] and the Talking Book [31] have shown tremendous success in developing regions, as the barrier to participation is minimal.

To show how Robit can be used to add a market layer for services and goods, we have modified an open source digital service application for challenged environments to use Robit for an auction-based marketplace. In addition, we have developed a standalone marketplace for buying and selling goods that takes advantage of the various features Robit provides. We will next briefly discuss the role Robit plays in these contexts.

A. Use case: digital applications

Poor connectivity in challenged networks makes downloading and uploading data very time consuming. There have been several attempts to address this problem, ranging from opportunistically prefetching content and storing it for later use [14] to employing peer-to-peer technology to cooperatively download data files and cache them for other users [30]. However, these solutions target data that is requested and consumed by multiple users. Each leverages redundancy in data requests to avoid fetching a piece of data several times, and delivers it from a local cache whenever somebody else requests it, thereby making future requests fast. Unfortunately, this approach does not help when the data requested is either personal, or only personally interesting. In these cases, the user can not expect for someone to have requested the data for her ahead of usage time, and has to wait while it is slowly transferred to the node. Sulula [28], an open source project from the University of Michigan, suggests a solution to this problem by extending the idea of individualized content distribution networks [9].

Sulula takes into consideration the wide availability of cellular phones in developing countries and personal usage patterns. Rather than visit a kiosk and fetch data on demand—a tiresome process at best—users request a *future visit* at a kiosk using their SMS capable cell phones. Sulula provides the secure infrastructure to fetch a user's private data from a data source to the consumption point ahead of usage time. When the user arrives at a provisioned kiosk, she need only obtain the session key on-demand, and thereafter has instant access. By scheduling data downloads and uploads with respect to resource availability, Sulula enables kiosks to manage their resources well, while saving users tens of minutes of waiting time downloading private data.

Sulula, however, requires users to establish business relationships with particular kiosks. For example, if a user knows of three kiosks that she might be interested in getting her data at, she needs to:

- Physically register at each kiosk, and establish a trust relationship with each one
- Know the contact information and services provided by each kiosk
- Individually contact each kiosk to see if capacity exists, and the prices are reasonable

This process is inefficient at best. Because users have the burden of contacting and comparing offers from kiosks individually, on top of having to pre-register at each one, competition in the marketplace is hindered. In addition, this mechanism makes Sulula difficult to use when individuals are mobile and do not have a frequented 'home' kiosk—severely limiting its utility to travelers, as were some of the authors in our recent visit to Ethiopia. Such users do not have pre-established business relationships with local kiosks of the visited area. Furthermore, Sulula requires each kiosk to be capable of having the facility to process and respond to SMS messages, which might require expensive gateways for busier kiosks. This can hinder the adoption rate by kiosks, and thereby reduce the number of service providers supporting the Sulula platform.

In the context of Sulula, Robit decouples the mechanism of providing service from the marketplace requirements of fostering competition and openness. As such, rather than users establishing business relationships with individual vendors, all communication is done through a central marketplace that facilitates the exchange of digital services. The marketplace serves as the convergence point where users and kiosk owners come together to trade, all done through low bandwidth communication and SMS messages. Vendors register with the marketplace and provide identifying information such as location. When a user would like to schedule data delivery, she contacts only the marketplace, describing her preferred location and estimated time of arrival, using SMS. Robit then takes over the request, and conducts a dynamic (real-time) auction for service providers in the preferred location. Vendors are allowed to fine-tune their offerings, run promotional periods etc. The scheduling mechanism at kiosks ensures that a kiosk can in fact service a request. Once offers are collected from various vendors, they are filtered and forwarded to the user. The user can consider various factors, such as location, price and timeliness of service, in deciding which kiosk to use and then informs the marketplace. The winner of the auction is notified, and the session key required for prefetching data is securely transferred to the kiosk. The user then can head to the location at the described time, knowing her data is ready and waiting for her.

B. Use case: standalone market

Robit was also used to build a standalone auction-based market for buying and selling goods. The auction platform allows merchants to run auctions for their goods, increasing the exposure of their items and the efficiency of trade, even in the face of poor networking conditions. Robit makes a number of adjustments to the vanilla auction infrastructure to adapt to the limiting constraints present in these environments. In addition to a simple SMS interface that allows users to accomplish a number of marketplace activities, Robit is augmented by a voicemail gallery system that gives participants the opportunity for more descriptive communication about the goods and services offered in the marketplace. Furthermore, to mitigate the lack of wide and on-demand communication channels, Robit auctions are structured around a right of first refusal rather than a contract to buy. We will discuss the auction structure of Robit in section II.

Our preliminary user study in Addis Ababa, Ethiopia, suggests a potential need for such a service. It is particularly difficult to buy and sell used goods, as most of the trade happens through word-of-mouth or brokers who charge steep fees for their services of bringing buyers and sellers together. In addition, comparison shopping requires visiting markets in different areas and finding similar items. We will discuss our initial user study and pilot deployment in section IV.

Robit provides a simple interface to its auction based digital marketplace, enabling buyers, merchants and vendors to exchange services and goods in a competitive environment. It is structured around the fundamental constraints present in challenged network environments, and leverages widely available tools to achieve its purposes. Robit can be used to make digital services like Sulula widely available to users without having to establish individual business relationships with all potential vendors. It can also be used to build an auction platform for exchanging other goods, and it provides a number of features and technologies that make the adoption easier in low-bandwidth, high latency environments.

II. Design

The main design principle behind Robit is providing an open and competitive marketplace by utilizing widely available communication channels in challenged environments. To this end, we limit the resources required to maintain and operate the infrastructure. Robit features an extensible structure, allowing various additional services to plug on top of the basic auction infrastructure. To demonstrate this, we will discuss the shim layer we built on top of Sulula that allowed it to benefit from the platform provided by Robit. In addition, we will discuss the various principles and mechanisms used in building a network challenged digital marketplace for use in developing regions.

To use the Robit infrastructures, digital services like Sulula provide small plugins at the market side as well as the end point, such as kiosks or business centers. The main principles in providing an auction platform for digital services are:

- Providing a transparent architecture to give users a simple way to purchase services
- Allowing for a real-time auction framework that can utilize up to date market information
- Operating without requiring users to have a pre-established business relationship with specific vendors once they are registered with the marketplace, and
- Fostering competition and openness

The market-side plugin for a digital service augments Robit with the service-specific logic to deal with requests. When requests are sent to the Robit listening component, they are forwarded to this plugin for further processing. In the case of Sulula, this layer checks with the data source that has data of interest for the user, and obtains meta information about available data for the user, such as the size of the data and a transaction key for further inquires. Using this information, the layer formulates solicitation for offers (SFOs) to pass to the marketplace. Once these requests are structured as SFOs, Robit contacts eligible registered vendors for their latest offers in providing service.

The dynamic bidding is handled at kiosks with the vendor-side plugin that provides the market functionalities to Sulula. This shim layer hooks into the Sulula stack to get the latest resource schedules and price offers set by the vendor, and responds to the SFO. A response to an SFO includes the price a kiosk is willing to accept for the data size specified, as well as the latest time it is able to service the requests. This information is collected from a number of participating vendors.

Upon receiving these offers, Robit passes back the most viable offers to the market-side plugin, which are recorded and passed on to the users. Users receive these offers in the form of a collective SMS message summarizing their options. A user responds using the unique identifier for an offer within a set limit of time in which the offer is good. Once an offer is selected, the winning kiosk is notified and securely given the transaction key so that it can download data. Data is transmitted from the source using the secure infrastructure provided by Sulula. The 128-bit Advanced Encryption Standard (AES-128) is used for block encryption and MD5 for hashing. Figure 1 shows the plugin architecture used by the marketplace.

Robit in addition was used to build a standalone marketplace for tangible goods in a community. Its low barrier to entry and low cost make it a good complement to the current status-quo of physical or word-of-mouth markets. In providing this standalone auction marketplace, the important design principles are:

- Building an easy and customizable interface to buying and selling
- Leveraging widely available technologies, and less reliance on good network connectivity
- Establishing a flexible market structure that leaves buyers and sellers in control of their business, and
- Self-sustaining the service with incentives for the marketplace operator

Participants in the standalone market are uniquely identified using their cell phone numbers. This establishes a somewhat permanent identifier that can be used to manage payments and communication. In addition, this allows for easy plug of micropayment systems such as M-PESA [26] into the system. The marketplace is structured such that sellers are charged a small fee to list their items. This fee can be adjusted based on operation expenses of the entity running the marketplace, or even waived if the service is provided by an NGO or a community organization. In either case, we believe enabling services to be profit oriented, or at least self sustaining, is a critical component of a lasting impact that stays longer than pilot study periods.

The standalone market has two main user-facing components. The first piece is an SMS-powered item listing and browsing component that enables buyers and sellers to come

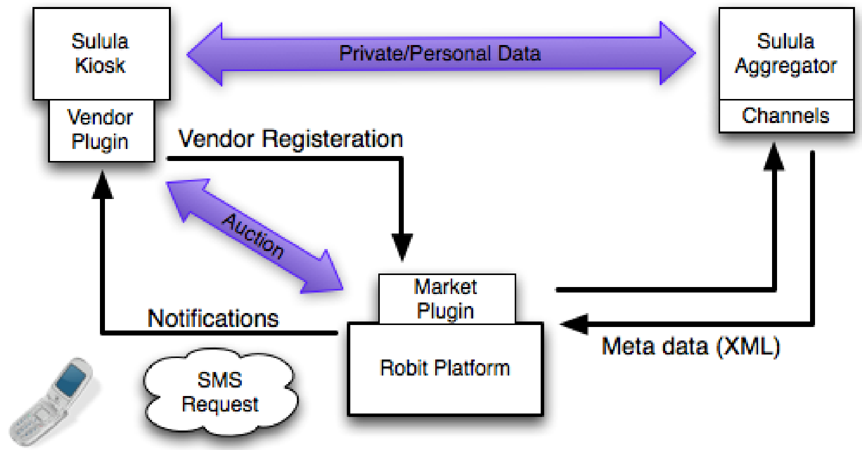

Fig. 1: Sulula retrofitted with the Robit platform

together around the marketplace. While we contemplated building a web-based market initially, we opted for the more widely available means in many of these environments. Listing an item on the market is a simple task that can be done with two text messages, one describing the meta-information about the item, such as name, reserve price, length of auction and location, and another giving more details about the item.

However, we realize that no sequence of SMS messages could provide enough information for buyers regarding the item for sale. As a result, the main purpose of the listing text messages is providing a searchable database that only describes the key identifying characteristics of an item. This infrastructure supports Unicode characters, and items can be listed and searched using the local SMS supported language. Ideally, such information will be augmented by pictures and video that describe the exact details of the item. However, this is not practical with the poor network conditions and the lack of access to internet communication for many people. For this reason, we augment the marketplace with a voicemail based product gallery that is used to further describe items.

Our simple voice based system is run concurrent to the marketplace. When a user lists an item for sale using SMS messages, it is given a unique auction ID and a corresponding PIN and encouraged to call the system. When the seller calls the system, she is asked for the ID and PIN of the auction, and allowed to record or modify the item description. The length of the description can be set by the market operator. Once this description is recorded, it is made available as an additional communication channel for buyers to learn more about the item.

When a buyer expresses interest in buying an item using a text message, given as a description of the item, with a preferred location and price range, Robit does a search for available item and provides a summary of the title and auction IDs of matching auctions. The buyer then can learn more about particular items by asking for the details available on the marketplace. Optionally, the buyer can also call the system to check if there is further voicemail description left by the seller, identified by the auction ID. While a voice description will not replace pictures, video or an in-person visit, it suffices to give the buyer a good idea about the item. Furthermore, by structuring the auction around the right for first refusal by a buyer, the Robit marketplace caters to the inherent information gap due to the narrow communication channel in these environments.

A. Auction Mechanism Design

Robit uses an auction design tailored specifically to address the aforementioned constraints associated with mobile marketplaces. Our auction mechanism adopts the second-price auction policy [40][1] : the highest bid buyer pays the auctioneer or the seller the second highest bid for the auctioned item that he or she wins. This payment system renders the second-price auction framework *incentive compatible*, meaning bidders' optimal bidding strategy is to bid exactly how much they value the auctioned item [18].

After examining the item in greater depth, the winner is permitted to withdraw from the auction without paying any penalty. This feature thus compensates for *information asymmetry*, when one side of the market has more information than the other, rising from the nature of the mobile marketplaces [3]. In other words, buyers' right of first refusal helps to prevent scenarios where sellers provide false information or purposefully create exaggerated impression about their items. Although revealing detailed item information to selective group of high-bid buyers and allowing them to resubmit their bids can also alleviate the effects of asymmetric information in Robit, such auction mechanisms require more time and effort from the buyers, thus discouraging them from bidding altogether.

[1]eBay, a prominent internet auction website, also implements its own version of second-price auction [29]

From the previous discussion, one may assume that Robit's second-price auction mechanism can eliminate strategic elements in buyers' bidding decisions, consequently improving the marketplace's ease of use. However, Robit's permission for auction winners to withdraw their bids violates this incentive compatibility property in the case of malicious bidders, whose interest is not to maximize their own utility but to crowd out as many buyers as possible. In particular, the enactment of the first refusal right may expose sellers and buyers to attacks by malicious buyers who can crowd out legitimate buyers by submitting artificially high bid and then withdrawing from the auction. The time and monetary cost of sending SMS messages and monitoring auctions may in part deter such behavior.

In order to further discourage these malicious buyers in high-priced items, we impose a refundable deposit requirement, $d \in [0, 1]$ of a buyer's bid, that will be collected at the beginning of the auction and returned in full when it concludes. To reserve the winner's right of first refusal in cases where later revealed details about the item do not meet the buyer's expectations, we always refund the buyers' deposit, regardless of the auction's outcome. This deposit requirement can further prevent malicious buyers from participating in several auctions simultaneously. In particular, our empirical study examines the effect of different deposit requirement levels d on social surplus for items of different values. We observe that buyers may benefit more from medium to high deposit rates, while sellers may not, prompting auction operators for Robit to determine their marketplaces' deposit rate that is optimal for both buyers and sellers. Note that although an entry fee will likely effectively deter this malicious behavior, we restraint from imposing extra barriers that may undermine Robit marketplaces' accessibility and usability. Payments and deposits could be made using existing micropayment facilities or through in-person dealings.

III. Implementation

Robit was implemented as a multithreaded standalone process that can be run even on low processing powered machines. The resource consumptions can be easily controlled and customized to the environment. Robit uses a number of technologies and has components written in C++, C# and Python. While Robit has a small barrier to entry, in terms of setting up the marketplace and running a small operation, it can also be easily scaled to meet the demands of more involved operations by employing additional resources and components.

The auction component of Sulula is mostly implemented using C# and the .NET platform. It has a number of subcomponents that define the various modules in the system that provide different functionalities. We used open source technologies whenever possible to reduce the time of development as well as increase the quality and reusability of pieces. The major components in the auction platform of Robit are the communication manger, the SMS manger, the search manager and the market manager.

The communication manager handles network based communications with other components in the system. It also provides an easy way to extend the communication channels to new components. In the context of Sulula, this component is used to manage the communication with various vendors, as well as data sources that have the private data that users are interested in. In the standalone market, the communication manager talks with components that deal with the voicemail gallery. As such, this component has to understand a number of protocols as it interacts with different entities. We make use of an open source XML-RPC package [7] besides other remote procedure call facilities present in the .NET platform.

The SMS manager deals with sending and receiving text messages, while communicating with the market manager that deals with the internals of the auction. We had a few options here. We could include a commercial grade SMS gateway that is able to handle high intensity traffic as used by several companies, or outsource the actual SMS sending and receiving using services like Twilio [36], which provide a simple way to integrate SMS in applications without dealing with SMS directly. However we wanted a simple and self-contained solution to begin with, which would allow for a quick deployment and small barrier to entry. On this front, some of the options were the Gnokii project associated with Nokia [15] and the MSR SMS Toolkit [39]. We decided to use the MSR SMS Toolkit because of its easy integration to .NET projects. The toolkit is an existing SMS gateway solution from Microsoft Research India, used to handle and respond to requests from users via a connection to an SMS sending/receiving port. The SMS toolkit is a simple programmable interface to SMS messaging, with hooks to applications that enable integration with various systems. A smartphone communicating with the processes running on a PC serves as the SMS sending and receiving port. Meanwhile, the phone can also be used for making and receiving calls.

The SMS manager has two subcomponents. One listens to and forwards requests, while the other operates a separate notification thread that provides current information to participants in the market. This is used to let users know when important events, such as auction closing or unlisitng, happen in the system. The SMS listener uses a command parser to interpret text messages and perform requested actions. Users are able to register, sell, bid, unlist, add and get details about auctions among other things.

The search manger performs guided search for users regarding items present in the marketplace. This is a crucial component because the opportunity for communication is narrow with buyers, as everything happens through SMS messages. This component indexes the title, location, price and detailed description of auctions and performs a natural language search guided by provided constraints. It ranks the found items using a relevance measure, while limiting for the preferred location and the price range buyers are looking for. A summary of the top (by default 3) matching items is given back to the user using an SMS message. This summary includes the auction ID, title, location and the current highest bid on the item along with the remaining time. The buyer then can either request for the detail or check if there is a voicemail gallery

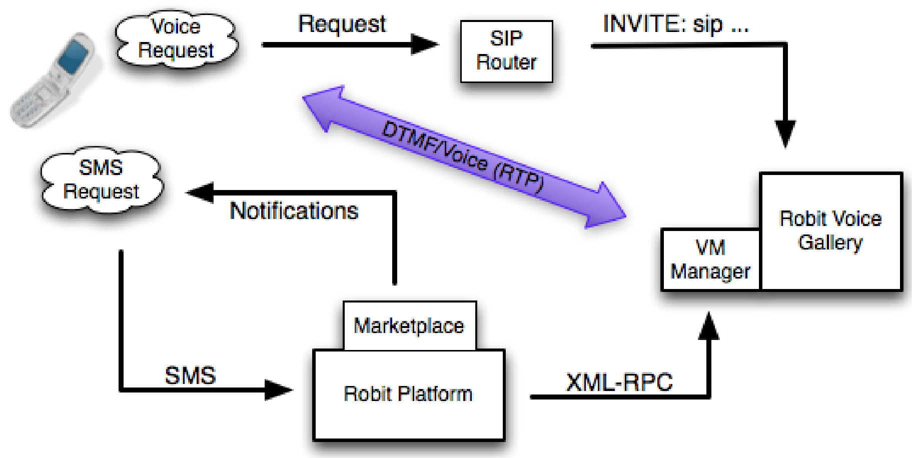

Fig. 2: Robit and the Voicemail Gallery

for the item. Currently, locations search is limited to city/town levels due to the lack of structured addresses and naming conventions. However, recent advances in mapping technologies for developing countries [23] provides a promising avenue for finer grained approaches.

The market manager is the component that implements the various auction strategies that were described above. At the bare minimum, it keeps track of open and closed auctions in the system, and performs needed system housekeeping. This component interfaces with the SMS manager to learn about requests as well as notify users of events. It interfaces with the search manager when identifying relevant auctions that a user might be interested in. It consists of two additional threads that monitor auctions that are nearing to closing time, and those transactions that have been completed and need to be logged for future reference.

Another important component in the marketplace is the voicemail gallery for items. This component implements an interactive voice response system that augments the main auction platform. With the increased adoption of VoIP, voice and telephony solutions are increasingly getting integrated with networked applications. This enables applications to have intuitive user interfaces that are very easy to customize to different cultures and environments. The Session Initiation Protocol (SIP) is at the core of many of these solutions, and our solution is SIP powered as well. We started with the open source SIP Express Media Server (SEMS) and SIP Express Router(SER) [32] projects, implemented mostly in C++, and added the needed marketplace features.

Calls to the system are switched using the SIP router, and terminated using the media server. The media server interacts with the marketplace to learn about open auctions, and assigned PINs for sellers. As users call the system, they are guided through customizable voice prompts to either check a voicemail gallery for an item, or create a new voicemail gallery for an open auction in the marketplace. Parts of this IVR system are implemented in Python that wraps the internal C++ modules. The prototype was run on a Pentium 3 machine with only 512MB of memory, and functions properly even on such low powered computers. Calling the voicemail system from the public switched telephone network (PSTN) requires an SIP-PSTN gateway, which is easy to implement, but could be pricey to start with. For pilot deployments, it is possible to use SIP compliant softphones which are widely available in internet kiosks as they are often used to make VoIP calls over the network. Figure 2 shows how the marketplace and voicemail gallery work together.

To make customization as easy as possible, all voice prompts are recorded as simple WAV files and placed in a user modifiable folder. Each prompt is clearly identified by a describing name, and customizing the prompt to a local language is only a matter of replacing the prompts with a different recording, while leaving a similar name. We have an Amharic (the national language of Ethiopia) customization of the prompts for use in our pilot deployment.

IV. Evaluation

We have evaluated Robit in a few different ways to analyze its utility in a challenged environment setting. We will first discuss the auction market simulations we did to compare how different deposit requirements affect auction outcomes and the social surplus created. We then discuss a user study we conducted in Addis Ababa regarding the utility of an auction based market place in developing countries like Ethiopia. The study gave us important insight into how conventional markets operate, and was important in revising our design for Robit. One of the interesting findings was the difficulty people have in buying and selling used goods outside of their social circles. Finally, we will describe a small in-country pilot deployment that is underway. Our local partners include a computer science graduate student in Addis Ababa and an internet kiosk operator. We were able to have local translations of user documents and a video tutorial that gives a quick overview of the Robit platform, as it pertains to the standalone market.

A. Auction Simulation

We empirically study how the deposit requirement $x \in [0, 1]$ affects the social surplus for two types of goods: high-valued and low-valued. In particular, we simulate a Robit market scenario of 100 buyers and 100 sellers who all sell the same good. Each seller s holds an auction for his or her one item, whose value r_s (from the seller's perspective) is also the auction's *reserve price*. Each buyer b is endowed with e_b dollars, and cannot borrow money at any time, guaranteeing $e_b \geq 0$. A randomly chosen subset of 20 buyers participate in each auction. It is important to note that we analyze the case where buyers are involved in several auctions at a time, which might be unlikely in the common case. However, in doing so, we focus on the interesting properties of the system in deterring malicious users who are trying to game the market. For most people who participate only in a handful of auctions at a time, the deposit requirement will have almost no impact, which is the intended purpose of the approach.

A buyer sends a text message to Robit asking for details about the item. Buyer b's valuation for seller s's item is specified as $x_{b,s} = v_b + \alpha_{b,s}$ where v_b represents b's average valuation for the good, and $\alpha_{b,s}$ reflects b's preference for the particular item sold by s. After sending his or her bid message to the seller, buyer b will be charged a deposit of $x_{b,s}d$, which will be refunded in full after the auction regardless of the final outcome. The seller then chooses the winner $b*$ and the final price x_s*, as described in Section II-A, and moreover, provides detailed item information to $b*$, which could involve an in-person visit. After considering this information, buyer $b*$'s valuation for the item is updated to $x'_s = r_s + \beta_s$. $b*$ will exercise the right of first refusal if and only if $x'_{b*,s} \leq x_s*$, and will pay for the item otherwise.

A Robit marketplace operator could charge a small fee for sellers to list their items. Since these charges are the sellers' fixed *sunk costs* [37], we will not include these listing fees in our analysis. The cost of sending a single SMS in Ethiopia, as provided by the Ethiopian Telecommunication Corporation, is around \$0.03 [12], and we use this value in our simulation. Note that each of the participating buyers in an auction sends at least two messages to first ask about the status of the auction and then to submit his or her bid. The winning bidder sends an additional message notifying whether he or she would like to pay for the item.

Our empirical study consists of two scenarios: in scenario A, the auctioned items have smaller values ($r \sim 4 \times N(1, 0.25), \beta \sim 3 \times N(1, 0.25), v \sim 6 \times N(1, 0.25), \alpha \sim 0.5 \times N(1, 0.25), e_b \sim 20 \times N(1, 0.25)$), while auctioned items in scenario B have higher values ($r \sim 21 \times N(1, 0.25), \beta \sim 3 \times N(1, 0.25), v \sim 22.5 \times N(1, 0.25), \alpha \sim 0.5 \times N(1, 0.25), e_b \sim 40 \times N(1, 0.25)$). We assign 5% of the buyer population as malicious; each of these malicious buyers will bid twice their valuation for the item. Note that malicious buyers do not necessarily withdraw their bids in all auctions, since they are charged the second highest bid price, and more importantly, are also interested in purchasing auctioned items like others. We calibrated the above parameters so that at least more than half of the auctions are successful on average in all settings, which mirrors the fact that a majority of items listed on popular auction sites are sold.

We evaluate the auctions' outcomes by three measures: i) seller surplus $\delta_s = \sum_s I_s(x_s * - r_s)$ where $I_s = 1$ if s sold his or her item and 0 otherwise, ii) buyer surplus $\delta_b = \sum_s I_s(x'_s - x_s*)$, and iii) social surplus $\delta = \delta_s + \delta_b$. As depicted in Figure 3, social surplus declines as the deposit rate increases in scenarios A and B, and so does buyer surplus. At the same time, seller surplus increases with d and levels off around $d \in [0.6, 1]$. Intuitively, higher deposit rates help to keep malicious buyers from crowding out legitimate buyers, and help the genuine buyers to win more auctions, resulting in more successful auctions. However, since malicious buyers are also interested in buying items whose final price is less than the buyers' valuations, their increasing absence also means lower final prices. In addition, fewer participants, both malicious and genuine, can submit bids for each auction as a result of higher deposit requirements. These concurrent effects therefore help explain the decrease in social surplus and in seller surplus and increase in buyer surplus for both scenarios A and B. An auction designer's job is then to choose the deposit rate that is acceptable to both buyers and sellers, while keeping the social surplus at a reasonable level.

B. Initial user study

We conducted detailed interviews with twelve people, ages 17 to 52, in Addis Ababa, Ethiopia to understand some of the everyday market issues they deal with. The group consisted of students, business operators, government and private sector workers. We asked about their buying routines and how they compare prices etc. New item purchases in the last three months for the participants ranged from clothing and shoes to mobile phones, computers, furniture and accessories. These are bought from either outdoors markets, such as *Merkato* in the heart of Addis Ababa, or shops and boutiques found throughout the city. All participants said they compare a few places before making a purchase, and they use their judgment of the quality of the item alongside the price point comparisons to decide between alternatives. A small number of participants also said they use the internet for items like computers to get a feel for what the price should be. This however gives only a ball park number as many factors are involved in determining the actual price at the marketplace. Price negotiation is an important part of the buying process. Only a few shops have fixed, advertised prices, and buyers have to negotiate and compare prices to get the best value. Anecdotally, of the several stores we visited in the city, fixed prices—very common in the US and many other countries—were found only in some of the high-end stores, and negotiation was the norm everywhere else.

Most of the participants also have bought used items in the past. These include electronics, furniture and home appliances.

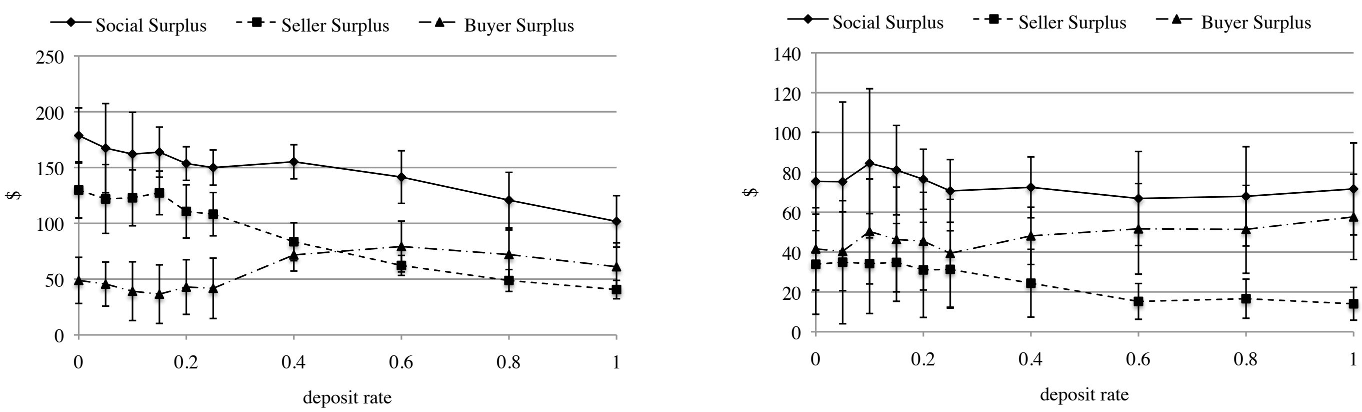

Fig. 3: Auction simulation results

Most of these are bought either through a social contact or through second-hand shops that buy and sell used items. Some participants also used brokers for this purpose. Price negotiations are even more important in this context because there are not enough similar items in the social buying circle to compare price points. Most of the people we interviewed have also tried to sell items at some point in the past. The process is similar in buying used items as it involves finding takers either through social circles and brokers or taking it to a used item shop for sell. A few people also mentioned posting the item and contact information on a notice board.

About half of the participants have used brokers for buying and selling items. The broker fee ranges from 2%-10% of the final selling price. Brokers are especially important in buying items that are not commonly traded, such as cars and large appliances. However, they are also used in making smaller purchases like mobile phones and personal computers. Experiences with brokers widely vary, but most people are content with the process, but for the sometimes steep prices.

All participants knew about auctions and about a third have participated in one. Auction notices are common on the national television and radio broadcasts, often advertised by banks and the customs bureau. Auctions are regarded as an excellent mechanism for getting the best prices for items because many buyers can participate and see the item for sale. The sentiment was particularly strong with those participants who tried to sell bigger items in the near past. Most of the participants were willing to try an auction based system for buying and selling their own items.

C. Pilot deployment

Following our user study and contacts in the country, we had set up a pilot deployment in Addis Ababa. Our local partners and volunteers were invaluable in preparing a local translation of our system. We started out by translating the Robit documents to Amharic. We also prepared a local language video tutorial that explains the key elements of the system, and relates it to the current experience. In addition, we have customized the voicemail gallery to operate in Amharic.

The pilot deployment took place in a local internet kiosk which was doubling as the market operator. This is one potential avenue for increasing the Robit adoption. Another alternative is for a separate entity, such as a local shop or small business, to administer the marketplace. We ran several mock auctions over a few weeks, while letting our volunteers try out the system and give us feedback.

The feedback we got was technical as well as social. The value a marketplace like Robit could bring to users was clearly noticed during our pilot deployment. A lot of people thought augmenting the system with a web component might also be useful as the those who have internet access could use it even better. We also got some feedback about the experience people had when interacting with the SMS interface. On the other hand, some suggested various modifications to the market process, including holding the item auctioned at the market operator, or adding a way to verify an item listed for sale indeed belonged to the seller. This was meant to deter stolen goods from being sold on the marketplace. Other feedbacks included enforcing timeliness and building trust on the system over time. These are essential considerations in full deployment of the service.

V. Related work

This section describes a number of projects that are related to our work. We will first give some background on the Sulula digital service platform, and how Robit enables it and similar digital services to take advantage of a market platform. We will then discuss other voice based and SMS solutions, including those that serve as community marketplaces. We will finish by discussing other market oriented solutions and how Robit relates to them.

There have been several projects looked at prefetching data for challenged environments, including DitTorrent [30] , which employs peer-to-peer technology to cooperatively download data files and cache tom for other users, and systems for opportunistically prefetching content and storing it for later use [14]. However, these solutions dealt with common data—data that is requested and consumed by multiple users.

Unfortunately, this approach does not work well when a user is dealing with private or personally interesting data that is not requested by other users ahead of use. Sulula [28] addresses this problem using a personalized content distribution system [9] by leveraging the wide penetration of cell phones in developing countries. Sulula provides a set of API's for building applications on top of its data distribution framework. To initiate a data transfer, the user sends a text message to a kiosk requesting data. For this to work, the user needs to have registered at he kiosk ahead of time. If the particular kiosk cannot service the request in time, is too expensive, or not in a close location at the time, the user has to keep asking other providers.

Our market benefits Sulula, and other digital services targeted to developing counties, by adding an auction based market platform which transforms one-to-one business transactions to a many-to-many environment that fosters competition and innovation. By providing the infrastructure, digital services that are interested in being traded on an open market need only provide plugins that adapt the marketplace to their needs. We were able to modify the Sulula framework to take advantage of the market platform within a reasonable period of time.

On the other hand, there are a number of voice based projects that enable communication within a community and can be easily shaped to the local needs. The main advantage of these systems is customization. The VoiKiosks [1] project from researchers at IBM India leverages their previous work in VoiServ [24] which mimics the structure of the WWW, but using voice. This is enabled through the Hyperspeech transfer protocol (HSTP) [2] which defines a protocol to seamlessly connect telephony voice applications. HSTP enables the users to browse across voice applications by navigating the Hyperspeech content in the application, which enables the building of voice enabled sites, called VoiceSites.

VoiKiosks used this technology to develop community specific voice based 'bulletin boards', where users can listen to and record messages. This approach is a response to the observation that the usefulness of the internet information for people in developing counties and the many villages within is very limited because relevant content is often not available in the internet [17]. One of the services VoiKiosks provide is an advertisement for professional services, where people can call in and post the services they provide and how to reach them, much like a classified ad on a magazine. Interested takers can then call the provider using the contact information.

Other voice enabled solutions targeted at developing countries include the Talking Phone project from Literacy Bridge [31] and the Freedom Fone [6] project currently implemented in Zimbabwe and South Africa. Robit builds on a number of principles from similar systems that showed that adding low-technology, but widespread interfaces to applications can boost its adoption in developing countries. We apply these lessons in the area of an auction-based marketplace that can be used for the exchange of digital services or tangible goods.

Ethiopia's recent commodities exchange [8], setup by a collaboration of the country's economists and engineers, is a market-based solution that is meant to address the unfairness and lack of information for farmers. Esoco/TradeNet [34], a beta project in West Africa, enables individuals to get current prices from commodity markets using an SMS platform. Trade at Hand [35] is a project funded by the UN's International Trade Center in Geneva, and provides daily price information for fruit and vegetable exports in Burkina Faso and Mali. Manobi [25] is another telecom firm based in Senegal that provides real-time agricultural and fish prices to fee-paying customers. BoonaNet [22] is a similar effort in Ethiopia for providing pricing information for commodities like coffee and teff using SMS in local languages. These and similar project are good examples of what open markets and information flow can bring to communities. Robit further extends these principles by providing an extensible auction-based plugin market platform that can be used for enabling digital services reach more customers, and build standalone markets for trading other goods.

VI. Conclusion

Open and competitive markets bring enormous value to communities. The internet has enabled such markets and changed how people buy and sell goods. However, these markets are not usually available in challenged network environments due to poor infrastructure and lack of relevant content. While some isolated solutions targeted to challenged environments exist, they are often confined to certain domains or communities. This paper described Robit, an extensible auction-based market platform for challenged environments. Robit incorporates ideas from economic and auction theories with widely available communication tools to create a market platform that can be used by developers in various applications. To demonstrate how Robit can be used to add a market layer to applications, we modified an open source data fetching application for challenged environments to use our system. In addition, we analyze a standalone auction-based market for tangible goods built atop Robit. Developers can build applications using Robit for a number of other domains such as commodity exchange, booking tickets and professional services among others.

In the future, we plan to extend Robit in a few ways. One such avenue is supporting auction centers. Currently, identity in the marketplace is tied to cell phone numbers. While this has a number of advantages, studies show sharing phones is a common practice in developing countries [4]. We plan to add a level of indirection to Robit such that identity can be established using some other credential in addition to a cell phone number. This will enable community auction centers where people can come and use a bidding service provided by a separate business to participate in auctions. Other avenues include supporting more services and local languages.

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