A Review of the Computer Science Literature Relating to Digital Financial Services

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Abstract

There is a growing literature on Digital Financial Services and Financial Services for the Poor as scholars in many disciplines seek to understand the opportunities and impact of mobile money and related financial products. One important area of work is how Information and Communication Technology can improve digital financial services (DFS) in terms of usability and security, strengthen infrastructure, and provide tools that allow operators to efficiently introduce financial services. In this paper, we survey the broad Computer Science literature to assess how this area has been studied from a technological perspective. We identify 46 works that have appeared in Computer Science conferences and journals. We provide an analysis of the areas addressed by the work and then identify five exemplar papers. The survey concludes with a full bibliography including short summaries of each paper.

1 Introduction

An efficient and effective financial system is critical to a community for its ability to facilitate economic transactions and serve as a vehicle for savings. Such activities provide both individual and communal benefits through the growth of economic activity and long-term planning capabilities at the individual level. However, many developing countries do not offer this provision; formal and reliable financial institutions are rarely available due to a variety of reasons including, but not limited to, a lack of infrastructure, funding, and oversight capabilities.

It is reported that 2.5 billion people in the world do not have access to a traditional bank account. Of those, 77% live on less than US$2 a day.[1] Supporting a family on such an income requires meticulous planning, and the environments that such families operate in leave little room for error—a financial shock in any form can result in permanent consequences to their financial and social situation.

Simultaneously, the global adoption of mobile technologies has supplied an opportunity to address this lack of financial inclusion. This is the intersection in which the Digital Financial Services Research Group at the University of Washington works. Our aim is to explore technologies that can assist banks and mobile operators in providing financial service products for the poor. As a starting point, we have conducted a literature survey revealing the current state of academic Computer Science literature surrounding mobile financial applications for the

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[1] http://www.worldbank.org/en/topic/financialinclusion

developing world. In doing so, we have gained insight on what aspects or technologies have already been studied or deployed. Additionally, this snapshot has allowed us to identify gaps in the current literature. These gaps serve as starting points for potential future contributions. We are not attempting a comprehensive survey of literature on Digital Financial Services, and recognize that many different academic disciplines are contributing to this area. We also are excluding from this survey the many reports and studies that are being produced by consulting organizations around the world.

Section 2 provides an overview of the Computer Science publishing environment and our methodology of researching in that space. Section 3 addresses our general impressions on the literature, with special consideration on the consistent themes and existing gaps we identified. As an extension of this, section 4 is a concise list of "Top Papers" that provides a comprehensive view of the papers we have examined. Each paper was chosen either for its unique insight or its marked representation of similar papers. Section 5 is an additional arrangement of our collection of papers into the challenge areas that each respective paper aims to address. We end with an annotated bibliography, which stands as its own contribution by capturing the current relevant research in the CS literature.

2 What is the CS literature?

This study aims to summarize the computer science research literature that relates to to mobile money and digital financial services (DFS). We considered research that directly addresses the financial sector in the developing world or indirectly supports development of such services. Our criteria for including a paper require that it touch at least two areas among mobile apps, financial services, and the developing world.

Most sub-disciplines of computer science focus on conference publications instead of journal publications, and our review reflects this. Although we strove to be as diverse as possible, we limited our scope to the top 2-3 conferences in each sub-discipline. Computer science conference rankings are a generally-accepted community decision, determined by a mix of criteria, including citation, paper submission, and acceptance rates.

2.1 Methodology

Our approach to selecting relevant papers is similar to strategies adopted by other literature reviews within computer science [26]. We compiled a list of conferences that were related to our topic. Our search was limited to publications from 2007 or later. The year 2007 was chosen because M-Pesa, one of the most successful branchless banking applications in the developing world, launched in 2007. We expect this would trigger research on the topic as M-Pesa could be used as a platform for relevant investigations.

To ensure that our paper list was comprehensive, we used relevant keywords to search in multiple computer science research paper repositories, including DBLP, ACM Digital Library and IEEE Xplore Digital Library. We also explored the citations and references of all the papers to find any previous or leading work within our scope.

2.2 Topic Areas and Conferences Studied

We surveyed top computer science publications across disciplines, including security and privacy, human-computer interaction (HCI), ubiquitous computing, mobile computing, networks and distributed systems, communication and signals, and computing for development. As expected, the largest contributions to research in DFS and financial inclusion come from the HCI and computing for development communities, though there is significant work in other disciplines, such as mobile systems. In particular, we believe this research is gaining momentum in the computer security community, as security is rapidly becoming a focus for many digital financial

service providers. A more thorough breakdown of every publication venue included in the literature review is in appendix A.

3 Main findings

When searching for studies with a focus on digital financial services, our overall impression is that the existing computer science literature is fairly sparse. Computing for development conferences, such as ICTD and ACM Dev, include financial studies on occasion, but even those venues have few studies focused specifically on digital financial services. Of the existing research studies, the majority are ethnographic case studies, relying on qualitative data, such as interviews, surveys, and the researcher's personal experience. Two topics which have received significant attention are user interfaces, through which customers engage with financial services, and secure authentication. These themes—ethnographic studies, end-user studies, and authentication—are discussed in detail in section 3.1.

These themes provide a valuable contribution that addresses many of the concerns identified as focus areas (see section 5), but it is possible that the research agenda is too heavily weighted toward these particular research topics and approaches, leaving other important avenues relatively unexplored. In our experience, reports from foundations, NGOs, and various consulting groups tend to emphasize the importance of robust and reliable agent networks, so it is surprising to see very little research on this matter. Likewise, network and cellular infrastructure is often cited as a significant barrier to digital financial services, but the systems and networks communities have not produced much work on this problem specifically in relation to financial services. The most glaring shortcoming, however, is the lack of quantitative data. The difficulty of data collection has almost certainly been a hindrance to widespread adoption of the topic in the research community. These gaps are discussed in more detail in section 3.2.

3.1 Common Themes

As mentioned previously, the prominent recurring topics in the literature are ethnographic studies, user interfaces for customer engagement, and authentication protocols to prevent fraud. While surveying the literature, these topics stand out due to their appearance in a large proportion of publications. We discuss each of these themes and present references around each topic. There are many papers which did not fit this mold, and there is also overlap between themes, particularly with ethnographic studies, but these very broad categories provide a "ten-word overview" of the current focus in the literature. Table 1 shows the full list of papers we consider within each theme.

Ethnographic Studies. Many papers related to our topic focused on or executed their own ethnographic studies. We identify four main categories for these papers: user interface, state of banking practices, security, and evaluation of new mobile money systems.

On user interfaces, Medhi et al. [19] compare the adoption and usage of mobile devices across India, Kenya, the Philippines and South Africa, while Medhi et al. [18] conducted usability studies in India comparing non-literate and semi-literate subjects on text-based vs. spoken dialog vs. rich multimedia interfaces. Hinman [15], Ghosh [13], Morawczynski [23], and Kumar [16] offer general overviews of the state of banking in their respective countries of study. In particular, they consider cultural and country-specific banking and payment practices, current roles of agents and their interactions with clients, and social perceptions or hesitations in adoption or continued usage of mobile money services. Blumenstock [6] looked at the impact of mobile money systems on savings. Two papers looking at novel implementations of mobile money were Ghosh [12] who studied a banking van, and Prentow [39] who looked at a micro-payments system. In regard to security of mobile money systems, Baraka [3] compares the technical security of SMS and USSD based systems and

Bilal and Sankar [5] use questionnaires to gauge perceived risks and compare them to known security risks. Along the nature of ethnographic studies, these papers offer more qualitative evidence than quantitative data.

User Interfaces and End Users. These studies focus on the interaction between the customer and the financial service. This often occurs through technology, such as mobile phones or ATMs, but these interactions also include agent-to-customer interactions and traditional teller-to-customer interactions. The computer science literature most often deals with emerging technologies, and user interfaces on mobile devices are most often the subject of study.

Several studies focus primarily on the user interface technology itself. For example, in a comprehensive evaluation of mobile capabilities, Balan et al. [2] evaluate the usability of fingerprint authentication and NFC for peer-to-peer transactions. For a more general overview of the capabilities of NFC, Meschtscherjakov et al. [20] design reproducible demonstrations to highlight many potential use-cases of NFC.

While these studies focus on the technological aspects of the interface, others focus on integrating novel user experiences into the broader design of financial systems.

Parikh et al. [36], for one, develop a novel interface that enables a mobile phone's camera to act as a management system for microfinance groups in rural India. Kaushik Ghosh et al. [14] design an interface specifically for semi-literate users and conclude that a paper complement to the digital system is the most promising approach. Moving toward the role of usable interfaces in security, Panjwani and Cutrell [34] design a friendlier authentication process and demonstrate its effect on end users.

Authentication and Fraud. The research dealing with fraud can be divided into three categories: login authentication, secure receipt confirmation, and end-to-end security. Headlining the importance of security research for financial systems, Ben-David et al. [4] published a call to action in 2011 for the security community to devote more resources and effort to the issues present in the developing world. There is still a lot of work to be done—for example, very little is known about the frequency and impact of fraud and other security exploits in the real-world ecosystem.

Reliable and usable authentication is a nuanced problem worldwide, and the developing world offers its own challenges. In this line of work, Balan et al. [2] evaluate an authentication scheme using fingerprints and NFC. Panjwani and Cutrell [34] examine the traditional PIN-based scheme and present practical security enhancements to the current model. Bilal and Sankar [5] and Ming Ki Chong [21] design their own authentication processes, guided by iterative feedback from qualitative user studies.

On the other end, significant attention has focused on the problem of confirming digital receipts. Panjwani et al. [35] argue that physical paper receipts offer many benefits to customers, and additional work from Panjwani [33] employs better receipt protocols as a means to reduce fraud in practice. Paik and Subramanian [31] develop a low-cost digital system for receipt tracking, and Sharma et al. [45] present a novel banking setup which relies on voice confirmation from both agents and customers in order to ensure reliable transactions.

Finally, practical end-to-end security may well be the holy grail for system architects, and current work has been gaining momentum. In particular, Reaves et al. [41] present an overview of many authentication flaws in existing Android applications, and Panjwani [32] gives a detailed description on how to achieve a secure network.

Research Theme	Relevant Papers
Ethnographic Studies	[6, 12, 13, 14, 15, 16, 18, 19, 23, 24, 25, 35, 36, 37]
Interfaces and End-Users	[2, 14, 20, 34, 36]
Authentication and Fraud	[2, 4, 5, 21, 31, 32, 33, 34, 35, 41, 45]

Table 1: A summary of the relevant work for each theme.

3.2 Gaps

Mobile banking relies substantially on the agent network. Ethnographic or technical evaluations on how agents operate, what challenges they face, how they game the system, and what could be done to streamline this part of mobile banking are largely missing from the Computer Science literature. This network controls the cash flow in and out of the system and could thus pose major risks to the adoption of mobile banking.

In recent years, several mobile banking applications have achieved astounding success, but quantitative data about these deployments is largely unavailable. Access to this data would lead to better understanding of the usage and impact of these services. For example, what is the adoption rate for personal versus business purposes? Numerical answers to such questions will help evaluate the barriers of entry and opportunities for improvement. Our understanding of the features offered by various services is also limited.

For developers, technical support around building mobile banking applications is lacking. These applications need good user interfaces with reliable security in an environment with intermittent network connectivity. Very little has been done to understand the main development challenges, how existing applications operate, and what threats exists against them. Such work could improve required tool kits and libraries that simplify the software development process and reduce the barrier of entry for new players.

User adoption depends on understanding how a financial application works and what fees are charged. Essential future research should include usability studies targeted toward understanding which authentication methods, user interfaces, and fee structures work best for semi-literate users.

4 Top papers

We selected a group of "top papers" to provide a representative view of the existing literature. Although each of these papers discuss significant research, we did not choose them solely on research merit; rather, they were chosen to encompass a variety of themes, challenge areas, and research disciplines. We do not necessarily claim that these are the "best" individual papers, but we believe they provide the best overview to a reader wishing to begin engaging with the computer science literature on digital financial services. We recommend reading these papers as a starting point or for a reader who does not have the time to explore the full depth of the literature.

Our selection of papers includes research from Panjwani's [33] work on receipt authentication, Balan et al.'s [2] peer-to-peer payment system, Reaves et al.'s [41] security assessment of mobile applications, Meschtscherjakov et al.'s [20] discussion of NFC technology, and Ghosh's [12] and Prentow et al.'s [39] evaluations of financial services delivered to rural areas using bank-operated vans. This list covers all themes discussed in section 3.1, and the papers discuss topics from many of the challenge areas presented in section 5. Additionally, these papers contain contributions from a variety of computer science sub-disciplines, including HCI, mobile systems, security, and computing for development.

Panjwani et al. [33] propose a system to avoid fraud caused by fake SMS receipts. The

proposed system uses missed calls as a way to confirm the legitimacy of actual receipts. When a user initiates a transaction with an agent, she sends a missed call to the bank to confirm that the agent indeed started a transaction. The user then receives a return message from the bank, verifying the transaction details. This protects the user from spoofed messages and incurs no extra cost to the user.

Balan et al. [2] present a design for a mobile payment application called mFerio. This work offers an extensive system that deals with a complete threat model and reasonable usability requirements. The application operates on a peer-to-peer network, uses fingerprints for authentication, and uses NFC for recipient identification. The authors focus on balancing security and usability, the design discussion, UI implementation, and a two-phase user study. This comprehensive approach—from initial design to user feedback—provides a holistic view of designing a mobile financial application.

The work by Reaves et al. [41] stands as the first security analysis of branchless banking Android applications. Through a manual analysis of seven financial service applications, they find systemic vulnerabilities in establishing secure connections, recording user data, and account access. Reaves et al. also review the application's associated user license agreements, which place an inordinate portion of responsibility on the customer in the case of fraud, theft, or sensitive information leakage. This work introduces many potential and realistic security issues in the market of digital financial services, and it paves the way for better security standards and analysis procedures.

Meschtscherjakov et al's [20] paper explores the viability of using NFC for mobile money systems such as contactless payment and digital wallets. Through a series of applications and demonstrations, each focused on a particular feature of NFC, they explore the use-cases of NFC and some potential concerns, such as ATM compatibility. TreasureHunt, a simple game demonstrating the basic NFC-enabled mobile phones' ability to recognize another mobile phone, demonstrates the speed of connection. HideAndSeek is an exercise using different conductive materials to shield the NFC. This addresses the situation where an adversary could secretly initiate transactions to nearby phones. CollectPoints is another exercise utilizing the proximity of two phones, but it shows the possibility of transmission interruptions, useful for thinking about interrupted financial transactions. RemoteControl demonstrates that one can start an NFC application remotely. Finally, the LongBeam exercise is used to consider the transmission speed of NFC. The authors find that there is a technical challenge with accommodating interoperability because the transmission speed decreases significantly as a result. Overall, this work is an example of exploring existing and new technologies to be incorporated into future DFS projects.

The research of Ghosh [12] describes a three month pilot study, known as "FinLit," in Uganda in eight rural and periurban areas that surveyed how customers, particularly those new to banking, used a combination of mobile phone and van-operated savings and transaction accounts. This pairs with a case study from Prentow et al. [39], which analyzes a token-based car battery-powered electronic micropayment system, used in emerging markets and rural areas. Both research papers focus on deployments in Uganda. Prentow et al. focus more on the technical details of this automotive-powered payment system, and Ghosh assesses the broader implications of using a system of vans to deliver financial services to the unbanked. The results of both are qualitative case studies, and it is clear that the systems were successful in introducing new banking services to previously unbanked individuals.

5 Challenge Areas in DFS

We give a list of challenge areas for work on digital financial services based on work by the Financial Services for the Poor[2] group at the Bill and Melinda Gates Foundation. These chal-

[2]http://www.gatesfoundation.org/What-We-Do/Global-Development/Financial-Services-for-the-Poor

lenges are another way to classify the existing research literature and examine missing pieces. We anticipate that these topics will be critical to the success of future DFS deployments, and classifying the current research according to these areas provides a clear picture of both the strengths and gaps of existing research. These key challenge areas are listed and described in this section, but for brevity we do not discuss each paper individually. That level of detail is included in the annotated list of references.

1. **Fraud -** As digital financial systems continue to scale, there will be increasing risks to both consumers and providers from counterfeiting, petty fraud, and unauthorized third-party transactions.

2. **Cyberattacks -** Networks and distributed systems are vulnerable to remote attacks related to communication spoofing, denial of service, and data breaches.

3. **Proximity payments and user payment experience -** Current payments solutions are slow (1min+) and taxing on consumers, requiring many steps and long numbers. This barrier to usability limits the potential to digitize the economy through this important channel and leads to customer mistakes.

4. **Usability -** For any emerging technology, being understandable and accessible to new users is a necessity. Even if a technology offers amazing benefits, it is worthless until it is adopted by users. Lowering the barrier for new users, especially the unbanked, to comfortably use DFS technologies will promote growth in financial inclusion.

5. **Identity and on-boarding -** Know Your Customer (KYC) requirements and lack of digital ID verification technology delay customer sign-up for DFS as does the difficulty of communicating value and convincing clients. Inputting customer data, verifying ID/biometric, and teaching customers about the product and its value to them are all major commercial challenges which often result in failure to enroll or low levels of active usage. Governments and bulk payers lack low-cost identification, authorization, and targeting mechanisms for social welfare disbursements.

6. **Analytics for product development and risk scoring -** Lenders, insurers, and other DFS providers have limited client data and poor analytics capability. This limits product design efforts and defeats credit and insurance risk profiling.

7. **Cash-In Cash-Out agent recruitment, training, and management -** With large, distributed agent networks, it is difficult for agent network managers to train agents to reach a consistent quality of service. Agents also have difficulty maintaining sufficient cash balances when banks are distant and have limited hours. Agent network management is generally the highest cost center for mobile money deployments.

8. **Financial management and budgeting by end users -** Poor clients find it hard to plan, budget, optimize, shield money from temptation, or avoid having it appropriated by others. This results in failures to achieve savings goals, debt, insufficient insurance, missed opportunities, high stress, and low asset accumulation.

9. **Infrastructure -** Lack of existing physical and digital infrastructure has been a barrier to services in rural and hard-to-reach regions. Research in this area may introduce novel ways of deploying new infrastructure, using the limited available infrastructure or designing technologies with less reliance on costly infrastructure.

Challenge Area	Relevant Papers
1. Fraud	[2, 4, 5, 21, 31, 32, 33, 34, 35, 41, 45]
2. Cyberattacks	[1, 2, 3, 8, 9, 10, 17, 22, 27, 30, 32, 41]
3. Proximity Payments	[2, 14, 20]
4. Usability	[18, 21, 34, 35, 36, 39, 40]
5. Identity and KYC	[45]
6. Data Analytics	[23, 42, 44]
7. Agent Management	[13, 24, 37]
8. End-user management	[6, 12, 16, 23, 35]
9. Infrastructure	[7, 11, 12, 28, 29, 38, 39, 43, 44, 46]

Table 2: The distribution of relevant papers by challenge area.

References

[1] Abunyang Emmanuel. Mobile Banking in Developing Countries: Secure Framework for Delivery of SMS-banking Services. Master's thesis, Radboud University Nijmegen, 2007.

This thesis reviews the GSM architecture and basic cryptographic practices and then proposes a secure protocol for SMS banking. The author also provides a prototype implementation of the proposed SMS protocol.

[2] Rajesh Krishna Balan, Narayan Ramasubbu, Komsit Prakobphol, Nicolas Christin, and Jason Hong. mFerio: The Design and Evaluation of a Peer-to-Peer Mobile Payment System. In *Proceedings of the Tenth Workshop on Mobile Computing Systems & Applications*, 2009.

The authors design a complete mobile peer-to-peer payment application, called mFerio, that uses fingerprints for authentication and NFC for recipient identification. The authors focus on balancing security versus usability, and the design discussion, physical UI implementation, and evaluative two-phase user study offer a comprehensive overview of an effective system.

[3] Baraka W. Nyamtiga, Anael Sam, and Loserian S. Laizer. Security Perspectives for USSD Versus SMS in Conducting Mobile Transactions: A Case Study of Tanzania. *Intl. Jour. Tech. Enhancements and Emerging Engineering Research*, 1(3):38–43, 2013.

A comparison of SMS and USSD shows that USSD offers better security and privacy, but the authors suggest that SMS may be better in the long run. A survey in Tanzania shows real manifestations of the discussed vulnerabilities, and the authors identify security weaknesses in all components of the network.

[4] Yahel Ben-David, Shaddi Hasan, Joyojeet Pal, Matthias Vallentin, Saurabh Panjwani, Philipp Gutheim, Jay Chen, and Eric A. Brewer. Computing Security in the Developing World: A Case for Multidisciplinary Research. In *Proceedings of the 5th ACM Workshop on Networked Systems for Developing Regions*, NSDR '11, pages 39–44, New York, NY, USA, 2011. ACM.

This paper is a call for security researchers to devote more focus to the context of the developing world. The authors motivate the need for security research in developing countries—not that the threats are necessarily greater; rather, that the developing world offers different issues, which are underrepresented in

the literature. In terms of financial services, the authors specify several mobile-specific issues.

[5] Muhammad Bilal and Ganesh Sankar. Trust and Security issues in Mobile banking and its effect on Customers. Master's thesis, Blekinge Institute of Technology, 2011.

Based on interviews and a methodical security analysis, the authors propose a fingerprint authentication scheme for mobile banking applications. The researchers' primary goal is to improve both security and usability, and the interviews focus on users' trust in mobile money systems.

[6] Joshua Evan Blumenstock, Michael Callen, Tarek Ghani, and Lucas Koepke. Promises and Pitfalls of Mobile Money in Afghanistan: Evidence from a Randomized Control Trial. In *Proceedings of the 7th ACM/IEEE International Conference on Information and Communication Technologies and Development*, ICTD '15. ACM, 2015.

Based in Afghanistan, this experimental trial examined the effects of disbursing employee salaries via a mobile money system. Findings suggest that the mobile payments system significantly reduced costs for the employer, but the behavior of employees showed no significant short-term changes. It is important to note that all employees in the study were office workers for an aid agency, so they do not necessarily represent Afghanistan's unbanked population.

[7] Amitsingh Chandele, Zahir Koradia, Vinay Ribeiro, Aaditeshwar Seth, Sipat Triukose, Sebastien Ardon, and Anirban Mahanti. 2g/3g Network Measurements in Rural Areas of India. In *Proceedings of the 3rd ACM Symposium on Computing for Development*, pages 50:1–50:2, New York, NY, USA, 2013. ACM.

This paper investigates the cellular data networks in India. It concludes that the data in unavailable in rural areas during the night, larger packet loss in general and stall duration is high because of the middle buffers.

[8] Kelvin Chikomo, Ming Ki Chong, Alapan Arnab, and Andrew Hutchison. Security of Mobile Banking, November 2006.

Like other work, this research identifies the security shortcomings of the GSM architecture and SMS. The authors propose ways to improve existing securities and also develop completely new protocols for SMS and GPRS.

[9] Sheila Cobourne, Keith Mayes, and Konstantinos Markantonakis. Using the Smart Card Web Server in Secure Branchless Banking. In Javier Lopez, Xinyi Huang, and Ravi Sandhu, editors, *Network and System Security*, number 7873 in Lecture Notes in Computer Science, pages 250–263. Springer Berlin Heidelberg, June 2013. DOI: 10.1007/978-3-642-38631-2_19.

To avoid attacks such as SMS spoofing, this work suggests a branchless banking system using an application directly on the phone's SIM card. This type of application is currently used in practice by several mobile network operators.

[10] Benjamin Davis and Hao Chen. RetroSkeleton: Retrofitting Android Apps. In *Proceeding of the 11th Annual International Conference on Mobile Systems, Applications, and Services*, pages 181–192, New York, NY, USA, 2013. ACM.

The authors propose RetroSkeleton, an Android application framework designed to rewrite fine-grained network access control within the application. This could be used to block unsafe content or implement HTTPS-everywhere functionality. RetroSkeleton does not require original source code, so it can potentially be used to improve the network security of existing applications.

[11] Amitava Ghosh, Sourya Joyee De, and Ambuj Mahanti. A Mobile Banking Model in the Cloud for Financial Inclusion in India. In *Proceedings of the 32Nd ACM International Conference on The Design of Communication CD-ROM*, SIGDOC '14, pages 3:1–3:9, New York, NY, USA, 2014. ACM.

This paper discusses the viability of financial inclusion in India through mobile banking. The writers suggest that mobile banking currently depends too much on external agents and recommend moving services to an IVR-based model. In this model, typical barrier-to-entry infrastructure costs can be outsourced using cloud services where costs vary with sales,

[12] Ishita Ghosh. The Mobile Phone As a Link to Formal Financial Services: Findings from Uganda. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development*, ICTD '12, pages 140–148, New York, NY, USA, 2012. ACM.

This study examines 8 locations in Uganda, observing how customers use mobile phone banking versus a banking van which visits each location once per week. One significant finding is that despite higher fees, users prefer transactional accounts over savings accounts. Overall, the author focuses on the scale, depth, and cost of potential financial services, and the main evaluation method is through customer interviews and surveys.

[13] Ishita Ghosh. The Agent in a Transformational M-banking Ecosystem: Interface or Intermediary? In *Proceedings of the Sixth International Conference on Information and Communications Technologies and Development: Notes - Volume 2*, ICTD '13, pages 33–36, New York, NY, USA, 2013. ACM.

This study focuses on the role of agents in the mobile banking system by the Indian bank Eko, and the analysis rests on interviews with agents and customers. The agents are arguably the most important piece of the mobile money system, yet this research details the difficulty of their job—they are the first to receive blame from customers, and the commission structures offered by Eko are not sustainable as a primary source of income.

[14] Kaushik Ghosh, Tapan S. Parikh, and Apala Lahiri Chavan. Design Considerations for a Financial Management System for Rural, Semi-literate Users. In *CHI '03 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '03, pages 824–825, New York, NY, USA, 2003. ACM.

This short talk describes the design process and results of designing a UI for community-based micro-finance institutions mainly comprised of semi-literate women. The authors conclude that information systems with a physical paper-based data format complementing the digital system are the most sustainable solution.

[15] Rachel Hinman and Julus Matovu. Opportunities and Challenges for Mobile-based Financial Services in Rural Uganda. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '10, pages 3925–3930, New York, NY, USA, 2010. ACM.

Through an ethnographic study of behaviors and attitudes toward finances in rural Uganda, the authors find that many locals have never used digital financial services despite being capable mobile users and having seen advertisements for mobile money. The participants claimed that they did not find utility in mobile money services. Recommended strategies for increasing the uptake of mobile

financial services in rural Uganda are to emphasize the features of the basic service and leverage teach-ability and share-ability among users.

[16] Deepti Kumar, David Martin, and Jacki O'Neill. The Times They Are A-changin': Mobile Payments in India. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '11, pages 1413–1422, New York, NY, USA, 2011. ACM.

Motivated by the development of a new Indian mobile payment system, deployed in 2011, this general ethnographic study seeks to understand how this new service may be adopted by users. The paper gives no comprehensive results, but rather offers different payment scenarios for people in India and discusses particular concerns over payment practices, such as the purchasing workflow, bargaining and haggling, and how payments are often time-critical. This work creates an excellent opportunity for additional follow-on studies.

[17] Kwok-Yan Lam, Siu-Leung Chung, Ming Gu, and Jia-Guang Sun. Lightweight Security for Mobile Commerce Transactions. *Comput. Commun.*, 26(18):2052–2060, December 2003.

Focusing on mobile internet, the authors argue that traditional internet security protocols, such as SSL/TLS, do not meet the unique needs of mobile users, such as the limited computation power of mobile devices. The authors propose a new communication protocol, but during the time since publication in 2003, the unique concerns have likely been nullified by the increased performance capabilities of modern devices.

[18] Indrani Medhi, S.N. Nagasena Gautama, and Kentaro Toyama. A Comparison of Mobile Money-transfer UIs for Non-literate and Semi-literate Users. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, pages 1741–1750, New York, NY, USA, 2009. ACM.

The authors conducted a two-fold study: (1) an ethnographic usability study of existing mobile services and (2) a usability study comparing non-literate and semi-literate subjects on text-based vs. spoken dialog vs. rich multimedia interfaces. They find that users prefer non-text designs, and the spoken-dialog is fastest and requires less assistance, while rich multimedia designs have higher completion rates.

[19] Indrani Medhi, Aishwarya Ratan, and Kentaro Toyama. Mobile-Banking Adoption and Usage by Low-Literate, Low-Income Users in the Developing World. In Nuray Aykin, editor, *Internationalization, Design and Global Development*, number 5623 in Lecture Notes in Computer Science, pages 485–494. Springer Berlin Heidelberg, July 2009. DOI: 10.1007/978-3-642-02767-3_54.

This paper studies the adoption and usage of mobile banking in India, Kenya, the Philippines, and South Africa and examines the differences between countries. The analysis is based on user studies and 90 qualitative interviews.

[20] Alexander Meschtscherjakov, Christine Gschwendtner, Manfred Tscheligi, and Petra Sundström. Co-designing for NFC and ATMs: An Inspirational Bits Approach. In *Proceedings of the 15th International Conference on Human-computer Interaction with Mobile Devices and Services*, MobileHCI '13, pages 422–427, New York, NY, USA, 2013. ACM.

This short paper outlines a joint industry and academia project wherein they created and tested several different applications to explore the different features

of using NFC. In exploring features such as identification of NFC-enabled devices, physical shielding properties, transmission interruptions, remote access, and transmission speed, the paper offers recommendations on how NFC may be enabled for ATMs and identifies security and efficiency concerns to consider.

[21] Ming Ki Chong. Usable Authentication for Mobile Banking. Master Thesis, University of Cape Town, 2009.

This thesis compares several methods for user authentication when logging in to a service: traditional PINs, graphical passwords, and a novel 3-D gesture system. The author evaluates the methods from both a security and usability perspective by conducting a user study with prototype models. The implications of this work are important in a development context, and it would be interesting to see a similar user study in the developing world.

[22] YoungGyoun Moon, Donghwi Kim, Younghwan Go, Yeongjin Kim, Yung Yi, Song Chong, and KyoungSoo Park. Practicalizing Delay-Tolerant Mobile Apps with Cedos. In *Proceedings of the 13th Annual International Conference on Mobile Systems, Applications, and Services*, pages 419–433, New York, NY, USA, 2015. ACM.

Cedos is a practical delay-tolerant mobile network access architecture in which one can easily build a mobile application. Cedos provides an API that conforms with TCP but transparently handles network disruptions and delays. This allows developers to more easily integrate their applications with complex network architectures.

[23] Olga Morawczynski, David Hutchful, Edward Cutrell, and Nimmi Rangaswamy. The Bank Account is Not Enough: Examining Strategies for Financial Inclusion in India. In *Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development*, ICTD '10, pages 24:1–24:11, New York, NY, USA, 2010. ACM.

At the time of this publication, nearly 60% of India's population had a bank account, but through a series of interviews, the authors found that many people who own a bank account do not have any balance and do not make any regular transactions. The authors argue that the percentage of population with bank accounts is not a sufficient metric for financial inclusion. Additionally, the interviews indicate that a lack of access to banks and inadequate financial education are prominent barriers to financial inclusion in India.

[24] Olga Morawczynski and Gianluca Miscione. Examining trust in mobile banking transactions: The case of M-PESA in Kenya. In Chrisanthi Avgerou, Matthew L. Smith, and Peter van der Besselaar, editors, *Social Dimensions Of Information And Communication Technology Policy*, number 282 in IFIP International Federation for Information Processing, pages 287–298. Springer US, September 2008. DOI: 10.1007/978-0-387-84822-8_19.

This case study examines the role of trust in user experience. It describes the fragile customer-agent relations and the strong trust between the customer and Safaricom, the mobile network operator.

[25] M.S. Sriram. Information Asymmetry and Trust: A Framework for Studying Microfinance in India. *Vikalpa: The Journal for Decision Makers*, 30(4):77, October 2005.

The author discusses the major barriers to delivering microfinances to the global poor. These include the customers' lack of trust in formal financial institutions

and the financial service providers' lack of information on transaction history and expected reliability.

[26] Nicola Dell and Neha Kumar. The Ins and Outs of HCI for Development. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, San Jose, CA, USA, 2016. ACM.

This literature survey provides a reference similar to our own study. The authors consider 259 HCI for development publications and discuss the evolution of relevant research.

[27] Baraka W. Nyamtiga, Anael Sam, and Loserian S. Laizer. Enhanced Security Model For Mobile Banking Systems In Tanzania. *International Journal of Technology Enhancements and Emerging Engineering Research*, 1(4):4–20, November 2013.

This paper builds upon the secure SMS system proposed in earlier work. Primarily based on evidence from deployments in Tanzania, the authors note that mobile network operators typically rely on inherent GSM protocols for security. The authors present an enchanced SMS security model, focusing on data encryption, user authentication, and message integrity.

[28] Earl Oliver. Characterizing the Transport Behaviour of the Short Message Service. In *Proceedings of the 8th International Conference on Mobile Systems, Applications, and Services*, pages 223–238, New York, NY, USA, 2010. ACM.

This paper proposes a data layer that operates over SMS. It examines variable transmission order, delay in transmission and loss of messages. It builds the protocol that consider all these variables and provides an efficient low bandwidth data transmission solution.

[29] M. Paik and L. Subramanian. ATMosphere: A system for ATM microdeposit services in rural contexts. In *2009 International Conference on Information and Communication Technologies and Development (ICTD)*, ICTD '09, pages 222–232. ACM, April 2009.

This research investigates rural banking via a network of ATMs, which communicate with banks via SMS. The authors provide an in-depth technical overview of the service, its potential reliability, and its security. Major limitations include physical security for the ATMs, potential legal restrictions, and power sources.

[30] Michael Paik. Stragglers of the Herd Get Eaten: Security Concerns for GSM Mobile Banking Applications. In *Proceedings of the Eleventh Workshop on Mobile Computing Systems & Applications*, HotMobile '10, pages 54–59, New York, NY, USA, 2010. ACM.

The author describes the outdated security standard currently in place for 2G GSM. Although modern mobile communications are moving toward more secure protocols, such as 3G GSM and LTE, many high-profile mobile money networks in the developing world rely on the vulnerable 2G standard. The author calls for a new open reference standard for these networks.

[31] Michael Paik and Lakshminarayanan Subramanian. Signet: Low-cost Auditable Transactions Using SIMs and Mobile Phones. *SIGOPS Oper. Syst. Rev.*, 43(4):73–78, January 2010.

This work addresses the problem of paper receipts, which are easily forged or lost but are nonetheless standard for both cash transactions and noncash exchanges in the developing world. The authors propose Signet, a new methodology for

managing digital receipts. The technical importance of Signet is that it leverages existing infrastructure and operates on familiar technology: SIM cards and mobile phones.

[32] Saurabh Panjwani. Towards End-to-end Security in Branchless Banking. In *Proceedings of the 12th Workshop on Mobile Computing Systems and Applications*, HotMobile '11, pages 28–33, New York, NY, USA, 2011. ACM.

This paper explains how end-to-end security is not present in current branchless banking applications, motivates the need for security based on an explicit threat model, and presents some initial work on improving end-to-end security in several different scenarios.

[33] Saurabh Panjwani. Practical Receipt Authentication for Branchless Banking. In *Proceedings of the 3rd ACM Symposium on Computing for Development*, pages 3:1–3:10, New York, NY, USA, 2013. ACM.

This paper uses missed calls as a way to confirm the legitimacy of receipts. When user a initiates a transaction with an agent, he/she sends a missed call to the bank to confirm that the agent indeed started a transaction. The user receives a return message from the bank, verifying the transaction and protecting the user from spoofed messages.

[34] Saurabh Panjwani and Edward Cutrell. Usably Secure, Low-cost Authentication for Mobile Banking. In *Proceedings of the Sixth Symposium on Usable Privacy and Security*, SOUPS '10, pages 4:1–4:12, New York, NY, USA, 2010. ACM.

The authors examine the PIN-based authentication technique used by Eko in India, and they propose a new method with better security guarantees. A user study indicates that the researchers' proposed method is more usable than the currently deployed system, but the sample size for the study is fairly small.

[35] Saurabh Panjwani, Mohona Ghosh, Ponnurangam Kumaraguru, and Soumya Vardhan Singh. The Paper Slip Should Be There!: Perceptions of Transaction Receipts in Branchless Banking. In *Proceedings of the 15th International Conference on Human-computer Interaction with Mobile Devices and Services*, MobileHCI '13, pages 328–331, New York, NY, USA, 2013. ACM.

This paper supplements a field study conducted in India on user perceptions and reactions of different receipt delivery mechanisms—particularly paper versus SMS receipt delivery. The study finds that many customers prefer paper receipts, and paper can actually increase efficiency and improve availability of agents in lieu of SMS failures. With concerns over agent abuse using paper receipts, the authors recommend allowing pull-based receipts and communicating information to users on receipt systems.

[36] Tapan S. Parikh, Paul Javid, Sasikumar K., Kaushik Ghosh, and Kentaro Toyama. Mobile Phones and Paper Documents: Evaluating a New Approach for Capturing Microfinance Data in Rural India. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '06, pages 551–560, New York, NY, USA, 2006. ACM.

Mobile phones have become a critical component of small business management, and this study focuses on an existing CAM user interface toolkit application that enables a phone's camera to act as a management system (e.g. send and receive paper documents) for microfinance groups in rural India. This study

focuses on usability aspects of the system and concludes that the mobile interface was efficient, accurate, and easy to adopt, rivaling the PC. Voice feedback and number-only data entry were particularly successful features.

[37] T.S. Parikh. Rural Microfinance Service Delivery: Gaps, Inefficiencies and Emerging Solutions. In *International Conference on Information and Communication Technologies and Development*, ICTD '06, pages 223–232. ACM, May 2006.

This paper overviews the three major barriers to sustainable microfinance in remote rural areas: (1) the exchange of information with remote clients, (2) management and processing of data at the institutional level, and (3) the collection and delivery of money to remote rural areas. This serves as a useful overview but may be several years out of date.

[38] Trevor Perrier, Brian DeRenzi, and Richard Anderson. USSD: The Third Universal App. In *Proceedings of the 2015 Annual Symposium on Computing for Development*, pages 13–21, New York, NY, USA, 2015. ACM.

The authors propose an open-source library for rapid development of USSD-based applications.

[39] Rasmus Prentow, Rasmus Steiniche, Simone D. Johansen, Jeni Paay, Ivan Aaen, and Jesper Kjeldskov. When Value is Greater Than Money: A Micropayment System in Uganda. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '15, pages 765–772, New York, NY, USA, 2015. ACM.

This case study reviews the development of a token-based car battery-powered electronic micropayment system, using an iterative design approach based on user feedback. The short write-up outlines the findings, some of which are insights into the preference of local symbols over words for interfaces and the importance of share-ability and teach-ability between community members.

[40] Aishwarya Lakshmi Ratan, Sunandan Chakraborty, Pushkar V. Chitnis, Kentaro Toyama, Keng Siang Ooi, Matthew Phiong, and Michael Koenig. Managing Microfinance with Paper, Pen, and Digital Slate. In *Information Technologies & International Development*, volume 8 of *ICTD '10*, pages pp. 67–83. ACM, June 2012.

The authors work with a self-help microfinance network in India to improve the quality of data records. They recommend a financial record management app built on low-cost digital slate, which can bridge the gap between going digital, improving efficiency and quality of these records while also maintaining usability and affordability for low-literate and low-income users.

[41] Bradley Reaves, Nolen Scaife, Adam M. Bates, Patrick Traynor, and Kevin R. B. Butler. Mo(bile) Money, Mo(bile) Problems: Analysis of Branchless Banking Applications in the Developing World. In *24th USENIX Security Symposium, USENIX Security 15, Washington, D.C., USA, August 12-14, 2015.*, pages 17–32, 2015.

In an automated analysis of Android applications for branchless banking, the authors find that a state-of-the-art analysis tool does not accurately detect many security shortcomings. The authors conduct a manual analysis of 7 such applications, and they find systemic vulnerabilities, including problems in encryption, authentication, and information exposure.

[42] S.K. Sathe and U.B. Desai. Cell Phone Based Microcredit Risk Assessment using Fuzzy Clustering. In *International Conference on Information and Communication Technologies and Development*, ICTD '06, pages 233–242. ACM, May 2006.

The authors take an informal community-based credit-assessment model and convert it to a cluster-based machine learning model. The authors prioritize the abilities to handle noisy, error-prone data and to function on hardware with limited computation capacity, such as mobile phones.The model parameters include features such as age, moral character, social status, enterprising nature, and loan history.

[43] Arjuna Sathiaseelan, Richard Mortier, Murray Goulden, Christian Greiffenhagen, Milena Radenkovic, Jon Crowcroft, and Derek McAuley. A Feasibility Study of an In-the-Wild Experimental Public Access WiFi Network. pages 33–42. ACM, December 2014.

This paper looks at providing publicly-accessible WiFi. The authors identify many challenges in providing such services, including geographically-sparse populations, concerns about security, lack of user interest, and prioritizing the cost of other living expenses over internet access.

[44] Asheesh Sharma, Manveen Kaur, Zahir Koradia, Rahul Nishant, Sameer Pandit, Aravindh Raman, and Aaditeshwar Seth. Revisiting the State of Cellular Data Connectivity in India. In *Proceedings of the 2015 Annual Symposium on Computing for Development*, pages 149–157, New York, NY, USA, 2015. ACM.

Investigating cellular data service in India, the authors find that many 2G and 3G telecom networks are misconfigured, resulting in low performance data connections. This is especially true in rural areas.

[45] Ashlesh Sharma, Lakshminarayanan Subramanian, and D. Shasha. Secure Branchless Banking. *3rd ACM Workshop on Networked Syst. for Developing Regions*, 2009.

The authors propose an alternative banking protocol, in which both the agent and the customer must first visit a physical bank. This method offers improved security and usability in some aspects, but it also suffers from additional limitations, such as requiring new customers to visit a bank.

[46] Lu Wei-Chih, Matt Tierney, Jay Chen, Faiz Kazi, Alfredo Hubard, Jesus Garcia Pasquel, Lakshminarayanan Subramanian, and Bharat Rao. UjU: SMS-based Applications Made Easy. In *Proceedings of the First ACM Symposium on Computing for Development*, pages 16:1–16:11, New York, NY, USA, 2010. ACM.

UjU is a platform for developing new SMS-based mobile applications. One of the examples given in this paper is a microfinance app used by the CAME institute in Mexico. This paper is relevant because it offers the CAME case study and focuses on SMS, an important technology for many mobile banking networks.

A Initial List of Publication Venues

The following list enumerates the publication venues that we initially considered when searching for relevant research on digital financial services. We searched through the proceedings of all listed conferences from 2007 to the present day, as described in the report methodology in section 2.1. Many papers from additional conferences and journals were included by following the citations after our initial pass through these primary conferences. Items marked with a

filled circle (•) had one or more relevant publications, whereas those marked with an empty circle (◦) were searched but did not contain any relevant work.

Computing for Development

- • **DEV**: ACM Symposium on Computing for Development
- • **ICTD**: Information and Communication Technologies and Development

Security and Privacy

- ◦ **IEEE S&P (Oakland)**: IEEE Symposium on Security and Privacy
- • **USENIX**: USENIX Security Symposium
- ◦ **CCS**: ACM Conference on Computer and Communications Security

Human-Computer Interaction (HCI)

- • **CHI**: ACM Conference on Computer-Human Interaction
- ◦ **CSCW**: ACM Conference on Computer-Supported Cooperative Work and Social Computing
- • **MobileHCI**: Human-Computer Interaction with Mobile Devices and Services

Mobile Computing

- ◦ **MobiCom**: ACM Conference on Mobile Computing and Networking
- ◦ **MobiSys**: ACM Conference on Mobile Systems, Applications, and Services
- • **HotMobile**: ACM Workshop on Mobile Computing Systems and Applications

Networks and Distributed Systems

- ◦ **NDSS**: Network and Distributed System Security Symposium

Communication and Signals

- • **SIGDOC**: ACM Special Interest Group on the Design of Communication
- ◦ **SIGCOMM**: ACM Special Interest Group on Data Communication