

Research Statement

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My research interests are in the areas of **networking** and **computing for development**. My research is driven by a strong desire to bridge the digital divide and make computing useful to the significant fraction of the world's population that lives in under-developed areas with very limited resources. My research specifically focuses on:

- *Extending Internet connectivity and enhancing the availability, reliability and usability of the Internet and the Web.*
- *Designing new computing solutions to address real-world problems pertaining to global social and economic development.*

Computer science, as a field, has largely focused on problems relevant to the developed world. The Internet and the World Wide Web have remained largely urban phenomena, which mean that a significant fraction of the developing world, especially in rural and underdeveloped regions, remains disconnected from the rest of the world. Bridging this digital divide requires us to address several important and challenging computer science research problems whose solutions will ultimately have significant impact on global development. Conventional computing solutions are often inappropriate in these emerging contexts due to various contextual factors including *lack of infrastructure, limited purchasing power, poor connectivity, limited power, language and literacy issues, and lack of local expertise for managing systems*. These unique infrastructure, cost, power and connectivity constraints create several new research challenges which often require a fundamental rethinking in the way we design computing solutions.

My research philosophy places a strong emphasis on “*end-to-end system design*” solutions for developmental problems. We use a three-step research process. First, we perform field-trials with various organizations in developing regions to understand the ground realities and identify challenging problems. Second, we design and implement cost-effective and appropriate computing systems that address the most difficult problems. Third, we deploy our systems in the developing world (with support from ground organizations), rigorously evaluate the system effectiveness and also perform impact evaluation studies where appropriate. Wherever viable, we seed startups to bring about large-scale, sustainable deployment. To date, three such startups have been created and a fourth one is being explored.

I joined as the first faculty member in NYU in the field of networking and together with Prof. Jinyang Li (who also joined in 2006), we established the **Networks and Wide-area Systems (NeWS)** group (<http://news.cs.nyu.edu>); the NeWS group has grown significantly to 11 PhD students, two postdocs and several MS students. To promote my research agenda in computing for development, I established the **CATER Lab** (<http://cater.cs.nyu.edu>), a multidisciplinary research initiative across Computer Science, Economics, Public Health and Public Policy. During the early stages of bootstrapping the NeWS group and the CATER Lab (2006-2008), I worked closely with three PhD students in the TIER group at UC Berkeley. More recently, in 2010, I worked with Prof. Yaw Nyarko (Economics) to establish the **Center for Technology and Economic Development** (CTED) at NYU Abu Dhabi (<http://cted.nyu.edu>). The CTED center at NYU Abu Dhabi has contributed immensely to the real-world success of many of our research projects in terms of planning deployments, conducting large-scale randomized controlled evaluations of computing for development solutions, establishing a strong cross-collaboration between CS and Economics students, and attracting excellent NYUAD undergraduate students to work with CTED. I am also co-leading the efforts to establish **SIGDEV**, an Association of Computing Machinery (ACM) Special Interest Group on Computing for Development. The flagship conferences of SIGDEV are the International Conference on Information and Communication Technologies for Development (ICTD) and the ACM Symposium on Computing for Development (DEV). ICTD and DEV have been co-located conferences since 2010 and together, they attract over 700 researchers from different sub-disciplines.

Next, I will describe my key research contributions and the impact of my work, grouped by research themes. Since all these projects are joint works with my students, I will use the words “we” and “our” when describing the research contributions.

1. Rural Connectivity

A significant fraction of rural regions remains disconnected with no network connectivity. Conventional wire-line connectivity solutions (fiber, broadband and dial-up) and wireless connectivity solutions (WiMax, cellular or satellite) are not economically viable for regions with low purchasing power and low user-densities. Achieving economic sustainability in the face of low demand imposes several practical design constraints: low network costs, low power consumption, high reliability and low management overhead. In contrast, cellular networks consume very high power and also face high capital and operational expenses (tower, power, management, spectrum). Achieving a combination of *high-performance, high reliability and low power consumption* is a fundamentally hard problem. Performance is often terrible in rural settings due to extremely poor signal quality at long-distances. A second factor that affects performance of wireless networks is interference. Rural regions lack stable and reliable power sources; grid power also exhibits significant fluctuations (between -1000 V to +1000 V) that result in high device failure rates. Finally, managing rural wireless networks is very hard due to problems with reliability and power and lack of local management expertise.

Our long term goal in the **Wireless Rural Extensions (WiRE)** project is to design an extremely low-cost, high-performance, low-power, highly reliable and easy to manage rural wireless network where the entire network is completely solar-powered with no dependence on the power grid. Addressing the rural connectivity problem has been a fairly massive initiative and this is joint work with several students at NYU and Berkeley (co-advised with Prof. Eric Brewer at UC Berkeley and Prof. Jinyang Li at NYU): Aditya Dhananjay (NYU CS), Matt Tierney (NYU CS), Wei Chih Lu (NYU-Poly), Rabin Patra (Berkeley), Sergiu Nedeveschi (Berkeley), Sonesh Surana (Berkeley), Ariel Nevarez (NYU ITP), Nahanaeli Schelling (NYU ITP), Meredith Hasson (NYU ITP). Together, we have made several important contributions that address many of the hard challenges in the WiRE network architecture vision.

One key component of the WiRE architecture is the design of high-performance multi-radio mesh networks to provide connectivity within rural regions. Achieving high-performance in a wireless mesh network is challenging due to self-interference across multiple hops. We have designed, implemented and evaluated **ROMA**, a practical distributed channel assignment and routing protocol which maximizes the end-to-end throughput between every node and a gateway in a multi-radio mesh. ROMA leverages non-overlapping channels along routing paths to achieve interference-free end-to-end paths and does not require nodes to operate on a common channel or use a centralized controller. ROMA explicitly uses routing information to assign distinct channels to different links on gateway paths to avoid self-interference, even when each node is equipped with only two radios. ROMA is well-suited to handle link quality variations and the topological differences between 802.11b/g and 802.11a links.

A second key component in the WiRE design is a high-performance wireless backhaul network powered by **Wifi-based Long-distance networks (WiLDNet)** to interconnect different rural regions. We developed WiLDNet, a point-to-point WiFi connectivity solution that can provide 6 – 10 Mbps over 50 – 100 kms at extremely low costs since it uses unlicensed WiFi spectrum and leverages off-the-shelf and widely available commodity hardware. WiLDNet addresses many of the fundamental protocol shortcomings of the conventional 802.11 MAC protocol in long-distance environments including: (a) extremely low link utilization; (b) failure of CSMA/CA, the standard collision avoidance mechanism in 802.11; and (c) inter-link interference across multiple directional links. WiLDNet can achieve sustained high-performance even when the underlying network experiences very high and fluctuating loss conditions (5-60% link loss rates).

To address the power and reliability challenges, we have developed a wide-range of hardware and software solutions which are low-cost and sustainable. These solutions include power monitoring modules, power stabilization and cleaning modules, solar panel monitoring systems, diagnosis backchannels, recovery mechanisms, device-level software reliability mechanisms and simple-to-use network management tools for non-experts. These solutions together significantly enhanced the reliability of our real-world wireless network deployments; the hardware failure rates of one of our networks in India came down from 35% to 0% over a 1-year time-period. One key component is a solar-panel monitoring system that enables us to rely completely on solar-powered wireless nodes and also monitor remotely the power characteristics of the various system components (panel, charge controller, battery, wireless nodes, load) and predict system failures in advance. This enables us to design highly reliable solar-powered rural wireless networks.

WiRE also supports an integrated naming and addressing layer that allows it to integrate seamlessly with existing cellular networks and also allow unmodified mobile devices to connect to the WiRE network. This work won the *Best demo award at SIGCOMM 2011*, a premier networking conference. As future work, we plan to investigate several directions including: cognitive network protocols for rural broadband, extending 802.11n (MIMO) to operate in long-distance environments, new power management and monitoring solutions, and understanding complex interference patterns between 802.11n MIMO, directional and omni-directional wireless network transmissions.

Impact: Our work on rural wireless networks has had significant impact in terms of publications, startups and real-world deployments. Several components of the WiRE architecture vision have been published in established venues: ROMA (Sigcomm 2009), WiLDNet (Mobicom 2008, NSDI 2007, Infocom 2007), Management of rural wireless networks (NSDI 2008), WiRE naming and addressing (Sigcomm 2011 demo paper – winner of best demo award) and Solar panel monitoring (ICTD 2010). WiLDNet has been deployed in over 10 developing regions around the world. The Aravind network in South India is scaling their network to provide *telemedicine services for over 500,000 users per year* by interconnecting 50 tele-centers using WiLDNet; this network also helped to prevent blindness through early detection of diabetic retinopathy for nearly 30,000 people in India. We also broke the world record for the longest point-to-point wireless link by achieving 6 Mbps over 382 kms in Venezuela. The AirJaldi network uses WiLDNet to provide *Internet access to 10,000 users in Dharamsala, India* (residence of Dalai Lama). Rabin Patra and Sergiu Nedeveschi (two PhD students who worked on WiLDNet) established **Tarana Wireless**, a startup that focuses on high-performance phased-array wireless chips for cellular network backhubs. Ariel Nevarez, Nahanaeli Schelling and Meredith Hasson worked on the solar panel monitoring platform and deployed their system in NYU Abu Dhabi and several rural households in Ethiopia. This team has recently established **Simbalink**, a startup to commercialize their solar panel monitoring system.

2. Re-architecting the Web for Emerging Regions

The World Wide Web is largely unusable or prohibitively slow for a majority of users in the developing world due to poor connectivity. In a large university in India with a good 8 Mbps downlink, we have frequently observed users experiencing page download times in excess of 120 seconds, which is exceedingly slow. The conventional model for Web access is fundamentally ill-suited for emerging regions due to four basic challenges. The first issue is the *sluggish growth in connectivity*. Akamai quarterly reports consistently indicate that the slowest growths in connectivity have been recorded in South Asia, South America, and Africa – three regions which account for the majority of emerging regions in the world. The second related issue is the growing *content-connectivity gap*. In contrast to connectivity, Web pages have grown in size and complexity over the past decade. The average web page size has grown roughly by a factor of 40-50 in the last decade. The third problem is the phenomenal growth in the number of Transmission Control Protocol (TCP) flows per web request resulting in a *TCP breakdown problem*. Standard browsers have evolved to optimize for opening multiple TCP connections (4-6) to each web server yielding as many as 30-50 competing TCP connections to download one page. This level of contention drives a majority of TCP flows in low bandwidth networks to operate in sub-packet regimes, where the fair share per flow is less than one packet per round-trip time. As a result, TCP completely breaks down resulting in extremely poor performance and an unusable Web experience. Finally, we also observed that conventional caching and network-level optimizations yield limited benefits in these settings.

We have proposed a new Web architecture for emerging regions that makes fundamental changes to different layers of the Web stack to enhance web access under different types of poor connectivity scenarios – low bandwidth networks, intermittent connectivity and offline access. This is joint work with Jay Chen (NYU PhD), Russell Power (NYU PhD) and Trishank Karthik (NYU MS). The design of our architecture revolves around two important design principles: (a) decouple web browsing interactivity from the underlying network; (b) expose the condition of the network to users in an actionable manner. To address the TCP breakdown problem, we have proposed the design of an in-network optimization engine (using middle-boxes) that uses a combination of flow aggregation, admission control, fair scheduling, and fine-grained packet prioritization to keep the admitted TCP connections from hitting timeouts. These mechanisms keep TCP operating as intended despite congestion introduced by pathological sharing, while requiring no software modifications at the end-hosts. In the absence of middle-box support, we found that pure end-host techniques involving tweaking of conventional transport

protocols (variants of TCP) yield very limited gains in terms of reducing congestion. For such scenarios, we have designed **Event-Logger for Firefox (ELF)**, a pure end-host optimization engine that is a simple browser-plugin which uses a combination of modified caching, prefetching and offline browsing to enhance Web performance.

At the application layer, our architecture provides two fundamental changes. First, we have designed a new *vertical caching layer* that enables end-hosts and proxies to organize cached content based on “topics” instead of the conventional model of caching using “URLs”. The idea of vertical caching is to maximize the utility of cached contents by exposing the “topics” of contents in the local cache to the user with the hope that the cache may still contain relevant information pertaining to the “topic” desired by the user. Second, we have designed **RuralCafe**, a system that explicitly exposes an asynchronous yet highly interactive web browsing interface and allows users to seamlessly navigate both live web content (as delivered by the network) and cached content (as delivered by the cache). In the extreme case of offline Web access, we proposed the design of a **Contextual Information Portal (CIP)** system where the goal is to deliver a vertical slice of the Web on specific topics (which are pre-specified) as an offline searchable and browse-able repository for users. We have designed a highly efficient mechanism to automatically construct CIPs for any given topic using a combination of two critical components: (a) a document classification engine that can determine with high accuracy whether a page is relevant to a topic or not with minimal training; (b) a focused web crawler that can efficiently crawl the web starting from a few authoritative pages to determine the vertical slice of the Web on a given topic. We found that the CIP concept is particularly useful as a tool for school education. We have developed CIPs for specific educational subjects based on the school syllabus in Kenya and India and have provided the system as an offline tool for teachers to use Web-based resources for enhancing school education.

As future work, we plan to explore several related challenges including: optimal congestion control protocol for low bandwidth environments, new models of semantic data compression, cost-aware network protocols, and new models of vertical caching for dynamic data. We are also working with economists on randomized control trials to measure effectiveness of the CIP platform for education.

Impact: This body of work has had extensive real-world adoption and impact, thanks to the phenomenal deployment effort of Jay Chen who lived in Kenya and India for 2-3 years during his PhD career so as to deploy these solutions in real-world settings. Several aspects of this body of work have been published in established venues: RuralCafe (WWW 2009), CIPs (WWW 2011, AAAI 2010), ELF (WWW 2011), Document Classification (AAAI 2010), TCP breakdown (SIGMETRICS 2011 short paper), Deployment impact evaluation (ACM DEV 2010, CHI 2009). The CIP work has been used by Strathmore University in Kenya to develop syllabus-specific CIPs for Kenyan schools to enhance education. This system is being scaled to be adopted by *nearly 60 schools in Kenya* (each with 200+ students). The CIP system has also been evaluated for effectiveness by expert teachers in India who have provided highly positive feedback on its impact on education. We are now working with economists in CTED, NYU to perform a large-scale *multi-year randomized control trial across 50-100 schools* in Ghana to study the impact of CIPs on education in comparison to textbooks. We are also working with Search Labs, Microsoft Research to integrate CIPs with their textbook-augmentation solutions to create a large-scale customizable Web-based educational platform for teachers and students. The Asynchronous web browsing and the vertical caching layer have been deployed in Amrita University in South India and we have also performed an impact evaluation of the system from this deployment. The low-bandwidth transport layer is currently being tested in Amrita University as well as in different low bandwidth network settings in Kenya. The ELF system has been deployed in a peri-urban school in Bangalore, India in joint collaboration with MSR India. Jay Chen has just completed his PhD and is exploring opportunities to establish a startup to promote large-scale adoption and impact.

3. Rethinking Mobile Information Services for Emerging Regions

A third important research challenge focuses on rethinking the way we design mobile information services for emerging regions. The last few years have witnessed a radical shift in the penetration and utility of mobile devices as a platform for new applications and services. In the context of emerging regions, we face three fundamental challenges which impose significant roadblocks to the introduction of new mobile information services. First, while the cellular revolution has made voice connectivity ubiquitous in the developing world, data services are largely absent or are prohibitively expensive in rural

settings. This basically limits *voice and Short Message Service (SMS)* to be the only available communication channels to a significant fraction of users. Both these channels are extremely bandwidth-limited with SMS messages being restricted to 140 characters per message. Second, despite the high penetration rates, a majority of users in these regions use *cheap low-end mobile devices* with restricted functionality due to purchasing power constraints. Finally, unlike the conventional western monthly flat-rate pricing model, most emerging regions use usage-based pricing and users are highly conscious of cost constraints. Hence, any mobile information service has to be highly *cost-aware* to merit adoption.

We have made several important contributions to enhance mobile services in emerging regions. We have developed **Hermes**, a data transmission mechanism that uses the voice channel as an acoustic modem to transmit data over the Global System for Mobile communications (GSM) voice channel. Surprisingly, this turns out to be a challenging problem due to several constraints. First, the acoustic channel is extremely narrow-band (400 Hz – 2500 Hz), which inherently limits the achievable data rates. Second, the voice codes used in cellular networks are hard to predict or model since the underlying network introduces several unpredictable distortions due to the use of memoryful codecs (each signal maintains memory of several previous symbols) and the use of several optimizations like voice activity detection and automatic gain control. Finally, a typical end-to-end voice call path in emerging regions with limited infrastructure may traverse a heterogeneous set of network links, thereby making the underlying voice channel effectively unknown. Hermes can achieve 1.2 Kbps over real cellular networks (narrowband channel capacity close to 2.5 Kbps) with very low bit error rates, while operating over unknown voice channels. Hermes uses a robust transcoding and frame recovery scheme to detect and correct errors in the face of bit flips, insertions and deletions. Hermes can also adapt the modulation parameters according to the observed bit error rate on the actual voice channel. When compared to SMS, Hermes can improve throughput by a factor of 5, while lowering the corresponding cost-per-byte by a factor of 50. This is joint work with Aditya Dhananjay, Ashlesh Sharma, Michael Paik, Jay Chen (all NYU PhD) and Prof. Jinyang Li.

When restricted to just the SMS channel, we show that one can design a wide range of useful SMS-based mobile applications. We have built **SMSFind**, an SMS-based search service that addresses the basic problem: how does a mobile user efficiently search the web using one round of interaction where the search response is restricted to one SMS message? This is a challenging research problem since the search response is restricted to only 140 bytes. Conventional SMS-based search services like GoogleSMS and Yahoo! OneSearch handle a limited set of pre-defined topics (weather, airport, restaurants etc.). SMSFind is specifically designed for the long tail of search queries that are spread across a wide range of topics. We evaluated SMSFind on a set of queries from ChaCha (a human-based mobile search service), and showed that SMSFind can correctly answer 57.3% of queries answered by a human while conventional automated search services like GoogleSMS could only answer 9.3% of the queries. This is joint work with Jay Chen (PhD).

To enhance the development of SMS-based applications, we have developed **UjU**, a mobile application stack that enables users to develop efficient and reliable SMS-based mobile applications quickly and easily. UjU significantly simplifies the design of new SMS-based applications on top of a common platform and users with no programming experience can build SMS-based applications quickly. To make efficient use of the underlying SMS channel and minimize operational costs, UjU supports a semantic compression layer that semantically encodes a structured stream and achieves a high compression ratio in comparison to standard compression techniques. As future work, we plan to explore several interesting problems including: a generic semantic compression engine for structured streams, new models for summarization search for mobile devices, cost-aware models for mobile web browsing and rethinking mobile data transport design. This is joint work with Wei Chih Lu (NYU-Poly MS), Matt Tierney (NYU PhD), Jay Chen (NYU PhD) and Faiz Kazi (NYU MS).

Impact: Hermes and SMSFind were both presented in Mobicom 2010 and UjU was presented at ACM DEV 2010. An earlier version of UjU was presented at SIGMOD 2009 as a demo paper. SMSFind has been deployed as a real-world mobile search service in Nairobi, Kenya in collaboration with Nokia Research. Hermes has been tested across multiple real-world cellular networks and can be used as a data-over-GSM modem for computers and low-end mobile devices. UjU has been adopted by several large organizations including: (a) *CAME*, a large microfinance organization in Mexico for a mobile microfinance application; (b) *Korle Bu Hospital* in Ghana for a pharmaco-vigilance system; (c) ICTPH, a health organization in India for a mobile data collection system. Wei Chih Lu, the lead developer of UjU, has formed **Toodhu Mobile**, a startup that focuses on the development of mobile applications and services for emerging regions. Toodhu Mobile is working with many health and microfinance organizations to create sustainable impact.

4. Low-cost Information Verification Mechanisms for Emerging Regions

Another important research theme has been the development of different low-cost and appropriate information verification mechanisms for emerging regions. Conventional mechanisms for identity and trust management may be inappropriate in under-developed areas due to several factors including cost, lack of infrastructure, lack of appropriate resources (such as computers, connectivity, etc.) or usability issues (semi-literate users). One of our focus areas has been *paper forgery*, which is among the leading causes of corruption in emerging regions. We have developed **PaperSpeckle**, a robust system that leverages the natural randomness property present in paper to generate a fingerprint for any piece of paper. Our goal in developing PaperSpeckle is to build a low-cost paper-based authentication mechanism for applications in rural regions such as micro-finance, healthcare, land ownership records, supply chain services and education, which rely on paper based records. Unlike prior paper fingerprinting techniques that have extracted fingerprints based on the fiber structure of paper, PaperSpeckle by using the *texture speckle pattern*, a random bright/dark region formation at the microscopic level when light falls on to the paper, extracts a unique fingerprint. In PaperSpeckle, we showed how to extract a “repeatable” texture speckle pattern of a microscopic region of a paper using low-cost machinery involving paper, a pen and a cheap microscope. Using extensive testing on different types of paper, we showed that PaperSpeckle can produce a robust repeatable fingerprint even if paper is damaged due to crumpling, printing or scribbling, soaking in water or aging with time. We have also extended PaperSpeckle to be able to fingerprint several different types of rough physical surfaces. Apart from PaperSpeckle, we have also developed other useful and appropriate information verification mechanisms for emerging regions. **Signet**, is one such system that leverages the computational power of security enabled SIM cards to perform auditable two party transactions. The PaperSpeckle project is joint work with Ashlesh Sharma (NYU PhD) and the Signet project is joint work with Michael Paik (NYU PhD). As future work, we plan to explore different physical verification applications for PaperSpeckle and also study the security of mobile banking solutions.

Impact: PaperSpeckle will be presented in ACM CCS 2011 and Signet was selected as one of the top papers from the SOSP NSDR 2009 workshop for Operating Systems Review. Ashlesh Sharma, the lead student on the PaperSpeckle project, has started **Entrupy Inc**, a new startup to commercialize the PaperSpeckle work. Entrupy Inc aims to focus on emerging regions to verify the authenticity of paper-based documents across different vertical markets.

5. Internet architecture and Social networks

Outside of the scope of developmental problems, I have also made important research contributions in the areas of Internet architecture and social networks. Here again, my research focuses on enhancing the reliability and resilience of Internet and Web-based systems. Within Internet architecture, I have worked on several projects which have focused on how to fundamentally redesign the Internet to address many of its shortcomings. The **Listen and Whisper** project explored the design of new security mechanisms to significantly enhance the resilience of BGP, the current de-facto inter-domain routing protocol of the Internet, against route hijacking attacks from misconfigured and malicious routers. The **Hybrid Link-State Path-vector (HLP)** project proposed a next-generation inter-domain routing protocol that addressed several shortcomings in the BGP protocol including scalability, churn, stability, convergence and security issues. The **OverQoS** project was among the first proposals that leveraged an overlay-based network architecture to provide an incremental and deployable approach for enhancing end-to-end QoS in the Internet without requiring any modifications to Internet routers. The **“One More Bit is Enough”** project provided a simple two-bit network feedback protocol to address one of the fundamental problems of Internet congestion control: how to design scalable and effective congestion control mechanisms for high bandwidth delay product networks.

Within social networks, we have studied the problem of how to leverage social networks to deal with different types of Sybil attacks (fake identities set up by adversaries) across different Internet and Web-based systems. We designed **SumUp**, a Sybil-resilient online content rating system that leverages trust networks among users to defend against Sybil attacks with strong security guarantees. SumUp addresses the basic vote aggregation problem of how to aggregate votes from different users in a trust network in the face of Sybil identities casting an arbitrarily large number of bogus votes. SumUp uses an *adaptive vote flow-aggregation mechanism* to limit the number of bogus votes cast by adversaries to no more than the

number of attack edges in the trust network (with high probability). By applying SumUp on the voting trace of Digg (online news voting site), we have detected strong evidence of attack on many articles marked “popular” by Digg. We extended the SumUp design to proposed **Gatekeeper**, a decentralized Sybil resilient admission control protocol that improved over prior work to achieve a near-optimal bound; Gatekeeper limits the number of Sybil identities admitted in a trust network to $O(\log \log n)$ per attack edge (link between Sybil and good identity) from the earlier result of $O(\log n)$ per attack edge. We have also designed **Credo**, a collusion-resilient credit based reputation system for P2P content distribution systems. These works together have provided a new toolbox of techniques for computing reputations in trust networks, which can also be applied in other contexts. As future work, we are investigating how our toolbox of reputation techniques can be extended to routing protocols, DNS, web page ranking and twitter ranking. SumUp, Gatekeeper and Credo are joint works with Nguyen Tran (NYU PhD) and Prof. Jinyang Li.

Impact: These works have been published in established venues: Listen and Whisper (NSDI 2004), OverQoS (NSDI 2004), HLP (SIGCOMM 2005), One more bit is enough (IEEE/ACM Transactions on Networking 2008, SIGCOMM 2005), SumUp (NSDI 2009), Gatekeeper (INFOCOM 2011, PODC 2010), Credo (Netsys 2009). The “Listen and Whisper” paper was awarded the **best student paper award at NSDI 2004** and has had an important influence in the design of secure routing protocols. This work was also presented at NANOG and WIRED meetings to network operators and network router vendors. The HLP, OverQoS and “One more bit is enough” projects presented radically different ways for enabling new services in the Internet and also addressed many of the fundamental shortcomings in the current Internet. Our work on social networks has influenced the ranking mechanisms of several online content rating sites (including Digg) especially to make them resilient to Sybil-identity based attacks.

Summary

My long-term goal is to fundamentally change the way we design networks and computing systems that address real-world societal challenges. Designing usable systems in the real world, especially in the global developmental context, raises a wide range of hard research challenges due to unique contextual factors and ground realities. My research has made important contributions to the following broad areas: rural connectivity, enabling Web access in emerging regions, mobile information access in emerging regions, low-cost information verification mechanisms, Internet architecture and social networks. I strongly emphasize an “end-to-end system design” in which most of our projects have moved beyond research prototypes to real-world deployments, some of which are transitioning to the stage of startups and larger-scale adoption. Many of these projects represent fairly large undertakings to execute in practice and I am indebted to all the help our group has received from the ground organizations, researchers and partners.