Research Statement

Weisong Shi
Wayne State University

I am a Charles H. Gershenson Distinguished Faculty Fellow and a Professor of Computer Science at Wayne State University (WSU), and direct the Mobile and Internet Systems Laboratory and Wireless Health Initiative at WSU. I am currently on leave with the National Science Foundation as a Program Director for the Computer Systems Program in the Division of Computer and Network Systems, Directorate of Computer and Information Science and Engineering. My research activities focus on networked computer systems, broadly spanning two related scenarios: mobile computing and distributed systems, with performance, privacy, power- and energy-efficiency as major concerns. In mobile computing, my research focused on automatic system adaptation in mobile environments, addressing the mismatch problem between resource constrained devices and content-rich services in heterogeneous environments, such as security, heterogeneity and energy. My research on distributed systems focused on resource management and scheduling in computing communities, such as P2P, Data Centers and Cloud, attacking the problems of performance, energy-efficiency and fault tolerance.

My main research contribution is in the field of distributed systems, Internet computing and energy-efficient systems. Here is a summary of my career achievements in terms of funding, publications, open source software, teaching and services. More details about research will be described in the following sections, while the detailed information about teaching and services can be found in my professional record and teaching statement.

- **Funding** I have been supported by a variety of governmental and industrial organizations, such as National Science Foundation, Department of Homeland Security, Air Force Research Laboratory, Gates Foundations, Swedish Research Council, Michigan Life Science Corridor, Great Lake Protection Fund, Chrysler and so on. Totally, I have been involved (as PI and Co-PI) in 11 externally funded projects and two research gifts, with a total of $6M, my share is about $2M. I was a recipient of prestigious NSF CAREER award.

- **Publications** I have published two books, 7 book chapters, 60 journal papers, 5 guest editorials, 89 peer-reviewed conference and workshop papers. As of December, 2014, according to Google Scholar, those papers have been cited 3500+ times, with seven papers have been cited 100+ times, and my H-index is 29. I was a recipient of four best paper awards, including 2012 IEEE Symposium on Workload Characterization, HPCCchina 2012, IEEE International Parallel and Distributed Processing Symposium (IPDPS) in 2005 and International Conference on Web Engineering (ICWE) in 2004. Recently, we won the Best Paper Nominee award at ACM 2014 Joint Conference on Pervasive and Ubiquitous Computing. The paper about SPAN (Software Power Analyzer) is one of the most cited articles in Elsevier Sustainable Computing journal.

- **Open Source Software** In addition to publications, Dr. Shi’s group has released several software artifacts that are widely used by the community, including CloudAligner, pTop, SPAN/Safari, and JIAJIA, which are widely used in the community. For example, CloudAligner, a MapReduce-based sequence aligning tool, has been downloaded 1200+ times since 2010, pTop, a process-level power profiling tool, has been downloaded 500+ times across 30 countries since 2010, SPAN, a software power analysis tool, has been
downloaded 46 times since May 2014. the JIAJIA software distributed shared memory system, which serves both as an open source research prototype and a practical parallel programming environment, has been installed in approximately 120 research institutions and universities, distributed in 20+ countries and regions around the world.

- **Teaching** I have been advising 18 Ph.D. students and 13 M.S. students in the last 12 years, and have graduated 11 Ph.D. students (two in academic) and 11 M.Sc students. I have supervised seven undergraduate students, four of them were supported by NSF REU supplemental program. I was the recipient of the College of Liberal Arts and Science Teaching Award in 2007 and 2011, respectively.

- **Services** Externally, I have served as the chair of the IEEE Technical Committee on the Internet since 2012, and serve as an editor of seven journals, including IEEE Transactions on Computers, IEEE Internet Computing Magazine, Springer Computing Journal, Elsevier Sustainable Computing, Journal of Computer Science and Technology, EAI Transactions on Collaborative Computing, and International Journal on Sensor Networks. I have been serving as the program co-chair of four international conferences, the funding co-chair of two workshops, and the guest co-editor of five journals, including IEEE Internet Computing Magazine and Journal of Parallel and Distributed Computing, and the organizing committee of more than 15 conferences. At NSF, I have played an instrumental role in organizing the NSF Workshop on Sustainable Data Centers (SDC), aiming to bring leaders from academia, industry and government to meet and discuss vision and challenges in the field. Internally, I have served on numerous departmental committees, including the interim chair search committee, and several university-level committees, appointed by President, Provost, and Vice President for Research respectively.

### 1 Funded Research

During my 12 years at Wayne State University, I was awarded about 11 external awards with a total budget of $6M, including $2M as principal investigator and $4M as a co-principal investigator in awards. The grants obtained as PI were awarded by federal agencies such as the National Science Foundation (CAREER Award, NeTS-NOSS, CRI, IPA), Air Force Research Laboratory, and industrial companies such as Huawei Technologies and Chrysler. The grant obtained as Co-PI was awarded by state agencies such as Michigan Life Science Corridor ($3,377,560, my effort is 10%), Department of Veteran Affairs ($200,000) and Gates Foundation ($100,000). I was also awarded a total of half million internal funds from Wayne State University, of which $132,748 was awarded through the university-wide faculty GRA competition.

After getting tenure (August 2008), I have secured six external grants and contracts as the PI and Co-PI, including one grant from NSF ($386,896, PI), one from Department of Veteran Affairs ($200,000, Co-PI, my share $80k), one contract from Gates Foundations ($100,000 direct cost, Co-PI, my share 60%), one contract from Great Lake Protection Fund ($577,999, Co-PI, my share is 15%), one contract from Sweden, funded by Sweden Council for Working Life and Social Research (2,100,000 SEK, Co-PI), one Air Force Research Laboratory SBIR subcontracts ($150,000, Sole PI) through Intelligent Automation Inc. The Air Force contract is built on the reputation-based trust model that we have developed in the past. Furthermore, our research group is actively collaborating with several groups from Huawei Technologies, the second largest Telecommunication company of the world, which gives us research gifts to support our research.

### 2 National and International Impact

My research has been recognized both at the national and international level. National recognition is illustrated by invitations to present our work at distinguished institutions such as Michigan State University, University of...
International recognition is illustrated by several invitations at universities and institutions abroad, including invited talks at several institutions and big IT companies such as University of British Columbia, Simon Fraser University, Chinese Academy of Sciences, Tsinghua University, Peking University, Zhongshan University, Tongji University, Huazhong University of Science and Technology, Xidian University, Baidu, Alibaba, to name a few. On November 2012, I was invited to give a keynote at Annual high performance computing conference in China (HPCChina 2012), which is the most prestigious conference in the China HPC community. In addition to the invited talks, I have also given over 30 other talks presenting our work at various national and international conferences. In addition, I have been invited to give talks at leading ICT companies, such as Baidu, Aliyun, Huawei Technologies, Taobao, etc. I was invited to serve as an expert of SoCAPS (the Society of Chinese American Professors and Scientists) summer USA-China delegation, supported by the Ministry of Education of P. R. China and SoCAPS. In December 2010, I was invited by the China government to attend the Outstanding Young Overseas Chinese Scholar Seminar (less than 100 people were selected from all over the world) in Guangzhou, China. Externally, I am currently serving as the editor of seven journals, including IEEE Transactions on Computers, IEEE Internet Computing Magazine, Springer Computing Journal, Elsevier Sustainable Computing, Journal of Computer Science and Technology, EAI Transactions on Collaborative Computing, and International Journal on Sensor Networks. SUSCOM is the first journal dedicated to sustainable computing. JCST is the most prestigious Computer Science journal published in English in China.

In 2012, I was elected as the Chair of IEEE Technique Committee on Internet (TCI). The goals of TCI are to sponsor high-quality workshops and conferences, provide timely information to Computer Society members and influence and promote internetworking standards. During my tenure, I have successfully bring 50% ownership of IEEE International Conference on Network Protocol to TCI. I will be serving as the program chair of 2016 International Green Computing Conference (IGCC 2014), and I have been serving as the program co-chair of four international conferences, including the 14th IEEE International Conference on Computational Science and Engineering (CSE 2012), the 8th IFIP International Conference on Network and Parallel Computing (NPC 2011), program vice-chair of two conferences, including IEEE AINA 2012 and ICPADS 2012, and the guest co-editor of five journals, including IEEE Internet Computing Magazine and Journal of Parallel and Distributed Computing, and the organizing committee of more than 10 conferences. I am currently serving on the steering committee of International Green Computing Conference (IGCC) and Network and Parallel Computing (NPC).

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The national recognition of my research contribution is also illustrated by the fact that I have been solicited by the National Science Foundation to serve as a Program Director in charge of the Computer Systems Research (CSR) core program within the Division of Computer and Network System, Directorate of Computer and Information Science and Engineering (CISE). At NSF, I am also serve as one of cognizant program directors for Smart and Connected Health (SCH), Cyber-Innovation for Sustainability Science and Engineering (CyberSEES) programs, Expedition in Computing (Expedition), and newly established NSF/Intel Visual and Experiential Computing (VEC) program. In addition, I have played an instrumental role in organizing the NSF Workshop on Sustainable Data Centers (SDC), which aims to seek the input from the community on three key questions: (1) What are the key research challenges for continued progress on sustainable data centers in the next 5-10 years; (2) What mechanisms can NSF foster to enable researchers in academia to obtain design information, traces, measurements, etc. from operating data centers to facilitate continued research; and (3) How can NSF best leverage its existing investments in cloud testbeds to these ends?

Internationally, my expert opinion has been solicited by the resource council of Hong Kong (China) and Qatar National Research Foundation, National Natural Science Foundation of China (NSFC), and Canada Re-
search Council. In all these cases, I have been consecutively requested to participate as an expert reviewer in the selection of research proposals for government funding.

My research activities have produced a number of software and tools, including JIAJIA, DYCE, RatingSim, CloudAligner and most recently pTop [13] and SPAN/Safari [65, 66]. CloudAligner, a MapReduce-based sequence aligning tool, has been downloaded 1200+ times since 2010, pTop, a process-level power profiling tool, has been downloaded 500+ times across 30 countries since 2010. The JIAJIA software distributed shared memory system, which serves both as an open source research prototype and a practical parallel programming environment, has been installed in approximately 120 research institutions and universities, distributed in 20+ countries and regions around the world. Some of them use JIAJIA to solve real world challenging applications. DYCE has been used by a number of users to generate dynamic Web content. The first paper on SPAN (Software Power Analyzer) is one of the most cited articles of Sustainable Computing journal. The SPAN software power analysis tool has been downloaded 46 times since May 2014.

Out of my 60 journal articles, 15 of them are published in IEEE/ACM Transactions, including Transactions on Computers (TC), Transactions on Parallel and Distributed Systems (TPDS), Transactions on Dependable and Secure Computing (TDSC), and so on, and six are published on Journal of Parallel and Distributed Computing (JPDC), one of the top two journals in parallel and distributed computing. Remaining papers are published in top journals in their respective fields according to the Institute for Scientific Computing (ISI) ranking: Pervasive and Mobile Computing, Sustainable Computing, Computer Networks, Performance Evaluation, Mobile Networks and Applications (MONET), Journal of Systems and Software, Cluster Computing, Journal of Web Engineering, IEEE Internet Computing, and so on.

My work has been cited more than 3500+ times by various authors\(^1\), including 191 times on the first paper of JIAJIA([21]), 182 times on CANS ([15]), 166 times on PET ([29]), 155 times on Preserving source location privacy ([68]), 126 times on trust inference ([30]), to name a few. My H-index is 30 based on the results from Google Scholar. Articles citing my work have been published in prestigious journals and conferences, such as IEEE Transactions on Parallel and Distributed Systems [19, 46, 73], IEEE Transactions on Computers [8], IEEE Transactions on Dependable and Secure Computing [70], ACM Transactions on Database Systems [12], ACM Transactions on Internet Technology [63], IEEE Transactions on Multimedia [18], IEEE Transactions on Wireless Communications [24], IEEE Transactions on Vehicular Technology [67, 72], Journal of Parallel and Distributed Computing [3, 10], USENIX NSDI [16, 41], USENIX USITS [47], as well as many other journals and top conferences [1, 2, 4, 7, 11, 14, 17, 23, 26, 27, 28, 34, 35, 42, 43, 45, 48, 50, 56, 58, 59, 60, 61, 62, 64], to name a few. My Ph.D. dissertation was awarded as one of the 100 National Outstanding Dissertations of China in 2002 (2 out of 100 are in Computer Science), sponsored by the Ministry of Education of China. This is the most prestigious award for Ph.D. dissertations in China. As part of this award, an extension of the dissertation (written in English) has been published by the Higher Education Press in 2004, which is the largest and most prominent publisher of educational books in China. (see http://www.hep.com.cn/cooperate/main.htm). The book titled “Foundations of Computer Systems Research” was published on October 2010, and has been adopted by several universities as the textbook.


\(^1\)The citation numbers are taken from the google scholar web site as of December 2014. Available at http://scholar.google.com.
3 Highlights of My Research

My main research contribution is in the field of distributed systems, Internet computing and energy-efficient computer systems. The core of my research activities is to investigate performance, trust management, privacy, power- and energy-efficiency issues of networked computer systems and applications. In this section, I describe seven representative research projects in the in the general area of networked distributed systems.

3.1 The JIAJIA DSM System (1996-2000)

Software Distributed Shared Memory (DSM) is an ideal vehicle for parallel programming because of its combination of programmability of shared memory systems and the scalability of distributed memory systems. However, the overhead of maintaining consistency in software and the high latency of sending messages makes achieving performance from software DSMs a challenging issue. My Ph.D. research focused on techniques for improving the performance from two perspectives: (1) reducing the frequency and time of communication entailed by coherence protocols, and (2) reducing the software overhead of each message operation.

By analyzing the disadvantages of snoopy and directory-based cache coherence protocols, we have proposed a lock-based cache coherence protocol [20] for scope consistency, and developed a software DSM system named JIAJIA [21] based on this protocol. The key idea of the lock-based cache coherence is the application of home concept to synchronization variables as well as to shared data. The protocol does not rely on the directory information to maintain cache coherence. Instead, all coherence related actions are taken through writing and reading write notices to and from the lock. In the context of JIAJIA, we have proposed several techniques to reduce these overheads in home-based software DSMs [22], including home migration mechanism to reduce remote data communication, which is the key challenge in home-based software DSM. In the home migration scheme, pages that are written by only one processor between two barriers are migrated to the single writing processor. Migration messages are piggybacked on barrier messages and no additional communication is required for the migration. Though very simple, performance evaluation with SPLASH program suite and NAS Parallel Benchmarks shows that home migration can reduce synchronization overhead dramatically and performance gains obtained by home migration arrange from several to hundreds percent compared to statically distributing home of shared data page-by-page across processors.

The first paper about JIAJIA ([21]) has been cited 191 times. All JIAJIA related papers have been cited more than 300+ times. JIAJIA has been downloaded and installed in more than 120 institutions around 20 countries in world. The JIAJIA system has been listed in many web sites, such as Wikipedia and University of California at Irvine.

My Ph.D. dissertation was awarded as one of the 100 National Outstanding Dissertations of China in 2002 (2 out of 100 are in Computer Science), sponsored by the Ministry of Education of China. This is the most prestigious award for Ph.D. dissertations in China. As part of this award, an extension of the dissertation (written in English) has been published by the Higher Education Press in 2004, which is the largest and most prominent publisher of educational books in China. (see http://www.hep.com.cn/cooperate/main.htm).

3.2 Dynamic Web Content Caching and Delivery (2001-2005)

Around 2001, Requests for dynamic and personalized content have increasingly become a significant part of Internet traffic, driven both by a growth in dynamic web services and a trickle-down effect stemming from the effectiveness of caches and content-distribution networks at serving static content. To efficiently serve this trend, several server-side and cache-side techniques have recently been proposed. Although such techniques, which exploit different forms of reuse at the sub-document level, appear promising, a significant impediment to their widespread deployment is (1) the absence of good models describing characteristics of dynamic web
content, and (2) the lack of effective synthetic content generators, which reduce the effort involved in verifying the effectiveness of a proposed solution.

In [55], we have conducted the first analysis of a personalized Web site, NYUHome, and derived several important implications on caching and delivery personalized Web content, including (1) Need for efficient delivery of personalized content; (2) Effectiveness of server-side fragment caches; (3) Potential for and likely benefits from using the object; (4) Benefits from proxy prefetching and/or server pushing composition technique; (5) Benefits from predicting access patterns; (6) Need for migrating channel generation functionality to edge servers; and (7) Need for customizing content based on network connection characteristics. A lot of efforts on dynamic and personalized Web content delivery were either directly or indirectly by these implications, as demonstrated by the 50+ citations.

In [51], we have proposed a set of models that capture the characteristics of dynamic content both in terms of independent parameters such as the distributions of object sizes and their freshness times, as well as derived parameters such as content reusability across time and linked documents. In our object modeling project, we addressed both of these shortcomings. Its primary contribution is a set of models that capture the characteristics of dynamic content both in terms of independent parameters such as the distributions of object sizes and their freshness times, as well as derived parameters such as content reusability across time and linked documents. These models are derived from an analysis of the content from six representative news and e-commerce sites, using both size-based and level-based splitting techniques to infer document objects. A secondary contribution is a Java-based dynamic content emulator, which uses these models to generate edge-side include (ESI) based dynamic content and serve requests for whole documents as well as separate objects. The paper that presented this work has been cited 60+ times.

We observed that future access to web-based content is likely to be dominated by two trends: (1) increasing amounts of dynamic, personalized content, and (2) a significant growth in “on-the-move” access using various mobile resource-constrained devices. We have proposed a novel architecture for CONsistent Nomadic Content Access (CONCA), which attempts to support, from the ground up, caching of dynamic personalized content for mobile users [52]. CONCA nodes are designed to reuse the shared portions of dynamic content, exploiting knowledge of user content access preferences to efficiently support transcoding and nomadic access (e.g., by prefetching) by assigning a home CONCA node for each user. Based on CONCA architecture, we have developed Tuxedo, a peer-to-peer cooperative Web caching system [54] for transcoded content. We have studied the benefit of peer-to-peer Web caching systems extensively, focusing on the dynamic Web content caching and delivery [38, 53]. The CONCA paper has been cited 34 times. The Tuxedo paper has been cited by papers that published at USENIX NSDI 2006 and 2007.

Furthermore, we have proposed a keyword-based fragment detection approach [5, 6], which takes original dynamic Web content and converts it to fragment-enabled content. Thus the dynamic parts of the document are separated into separate fragments from the static template of the document. This is dependent on our proposed keyword-based fragment detection approach that uses predefined keywords to find these fragments and to split them out of the core document. Our second proposal, an augmentation to the ESI standard, allows splitting the information of the position of each fragment in the template from the template data itself by using a mapping table. Using this, a fragment enabled cache can have a more fine grained level of identifying fragments independent of their location on the template, which enables it to take into account fragment behaviors such as fragment movement. We used the content taken from three real Web sites to achieve a detailed performance evaluation of our proposals. Our results show that our keyword-based approach for fragment detection and extraction provides us with cacheable fragments that, when combined with our proposed mapping table augmentation, can provide significant advantages for fragment-based Web caching of existing dynamic Web content. This paper won the Best Paper Award of the 2004 International Conference on Web Engineering (ICWE), accept rate is 12% in year 2004. ICWE is the most prestigious conference on Web Engineering.

Community computing — federated sharing of dispersed pools of geographically distributed computing resources under coordinated control—has been considered as a promising platform for solving large-scale problems in science and engineering. However, resource management in these environments is a complex undertaking. These systems need effective mechanism for fair sharing of community resources, adaptability to dynamic changing conditions, prevention of denial-of-service (DoS) attacks, and coordination of the diverse policies, cost models, and varying loads different peers. As one motivating example, a classical “tragedy of the commons” for peer-to-peer file sharing is 50 to 70% of peers are free riders, which results in a great load imbalance of the systems. Resource trading can enforce a cooperative approach for the resource sharing and is promising to address the above problems. The autonomous, heterogeneous, and decentralized nature of participating peers across multiple administrative domain introduces two challenging issues related to resource trading: decentralized trading scheme, which means the decision of resource exchange and negotiation is determined by each peer based on its personalized view of the partner and its own policy; self-policing personalized trustworthiness management, which means different peers may have different opinions on the trustworthiness of the same peer, instead of unique global trustworthiness value like eBay.

In 2005, we propose to develop a trustworthy trading approach that consists of two models: M-CUBE, a Multiple CUrrency Based Economic model, as the decentralized trading scheme, and aPET, an adaptive PErsonalized Trust Model, to provide the trustworthiness of the peer to support M-CUBE. The M-CUBE model provides a general and flexible substrate to support most of high level resource management services required by the P2P computing, such as resource co-allocation, quality of service (QoS) control, advance reservation and scheduling algorithms. aPET derives the trustworthiness from the reputation evaluation and risk evaluation. The trustworthiness value provided by aPET will be treated as the view of the peer by M-CUBE. The unique feature of our approach is seamless integrating the trustworthiness and dependability of peers into the resource trading.

PET models the reputation as the accumulative assessment for the long-term behavior, treats the risk as the opinion of the short-term behavior, and makes both of them quantified. The weights of the reputation and risk are adjustable according to different environments and requirements, which distinguishes PET from the previous work. Our evaluation results show that both reputation (long-term behavior) and risk (short-term behavior) are important in designing a personalized trust model. The results also show that the PET model is flexible enough to adapt to different applications by adjusting the weights of the reputation and the risk.

The original PET paper is one of the earliest work in the field, and has been cited 166 times to date. We have successfully applied the trust models to two applications: ISP peering and Grid resource management.

In ISP peering, the fragility and the poor resilience of Internet are manifested by the severe impact of network activities and the slow recovery after the earthquake damaged undersea cables and disrupted telephone and Internet access in East Asia in December 2006. Except the inefficiency of routing protocol, lack of efficient network monitor mechanisms and economic incentives to encourage the service providers to act cooperatively and promptly is another important reason. In this work, we build a trust-based economic framework called TRECON to address these open problems in Internet routing [32]. The novelty of TRECON is combining an adaptive personalized trust model (aPET) with an economic approach to provide independent trust-based routing among service providers. TRECON provides flexible policy support based on the trust-based economic mechanism so that autonomous organizations with varied interests and optimization criteria can be smoothly integrated together to achieve better adaptiveness and self-management. Through introducing the economic model, TRECON explores a new way to solve the economic problems and incentives issues in the collaboration among service providers. To show the flexibility of routing policies support, we propose four typical routing policies under the TRECON framework. We evaluate our approach by comparing these four trust derived routing policies with the classical global shortest path routing (SPA) approach. We find that the policy based on trustworthiness (TRU) performs much better than all other policies under different network topologies in terms of delay, success delivery rate, and economic effects.
The obstacle for the Grid to be prevalent is the difficulty in using, configuring and maintaining it, which needs excessive IT knowledge, workload, and human intervention. At the same time, inter-operation amongst Grids is on track. To be the core of Grid systems, the resource management must be autonomic and inter-operational to be sustainable for future Grid computing. For this purpose, we introduce HOURS [31], a reputation-driven economic framework for Grid resource management. HOURS is designed to tackle the difficulty of automatic rescheduling, self-protection, incentives, heterogeneous resource sharing, reservation, and SLA in Grid computing. In this work, we focus on designing a reputation-based resource scheduler, and use emulation to test its performance with real job traces and node failure traces. The results demonstrate that our scheduler can reduce the job failure rate significantly, and the average number of job resubmissions, which is the most important metric in this paper that affects the system performance and resource utilization from the perspective of users, can be reduced from 3.82 to 0.70 compared to simple sequence resource selection. This has the huge potential to improving resource utilization and reducing cost.

This project had been funded by National Science Foundation as my CAREER Award. The first paper ([29]) on the proposed personalized trust model has been cited 166 times since it has been published in 2005. The Rating-Sim software, a free simulator for evaluating different rating algorithms, has been used by many colleagues worldwide since its release in later 2006. In the context of trust models, we have systematically analyze the effect of ratings in trust inference in open environments, including algorithm uncertainty and factor uncertainty [30]. This work, to our knowledge, is the first effort of this kind, and have a big impact of the future research on trust inference and rating aggregation as evidenced by the wide citation (more than 120 citations).

In 2010, together with Ling Liu from Georgia Institute of Technology, I organized a special issue on Trust and Reputation Management on IEEE Internet Computing.

3.4 Privacy-Preserving in Mobile Sensing Systems (2005-2013)

We have been working on the privacy issues in mobile sensing systems since 2005, where subjects move frequently in the system, i.e., vehicular networks and animal monitoring. Vehicular networks have attracted extensive attentions since 2002 for their promises in improving safety and enabling other value-added services. Most previous work focuses on designing the media access and physical layer protocols. Privacy issues in vehicular systems have not been well addressed at around 2005. We argue that privacy is a user-specific concept, and a good privacy protection mechanism should allow users to select the degrees of privacy they wish to have. To address this requirement, we are one of the first groups to propose the notion of “adaptive privacy” [49]. The key rationale behind adaptive privacy is that the privacy requirement of a user should be adaptive, depending on the context and user preference. This original work has opened a new research direction, as evidenced by more than 50 citations in the last few years. Furthermore, we have proposed a privacy-preserving authentication to address the security and privacy issues that are required by many modern applications, such as vehicular networks. The key contribution is a random keyset based authentication protocol that preserves user privacy under the zero-trust policy, in which no central authority is trusted with the user privacy [69]. We show that the protocol can efficiently authenticate users without compromising their privacy with theoretical analysis. Malicious user identification and key revocation are also described. The original paper of this idea has been cited more than 60 times.

In the area of location privacy in wireless sensor network-based monitoring applications, we first described a successful attack against the flooding-based phantom routing, proposed in the seminal work by Ozturk et al. Then, we proposed GROW (Greedy Random Walk) [68], a two-way random walk, i.e., from both source and sink, to reduce the chance an eavesdropper can collect the location information. We improve the delivery rate by using local broadcasting and greedy forwarding.n Privacy protection is verified under a backtracking attack model. The message delivery time is a little longer than that of the broadcasting-based approach, but it is still acceptable if we consider the enhanced privacy preserving capability of this new approach. At the same time, the energy consumption is less than half the energy consumption of flooding-base phantom routing, which is
preferred in a low duty cycle, environmental monitoring sensor network. This work is one of the earliest work in the field and has been cited by more than 155 times since it was published in 2006.

In the area of participatory sensing, we argue that while participatory sensing can benefit the individuals and communities greatly, the collection and analysis of the participators location and trajectory data may jeopardize their privacy. However, the existing proposals mostly focus on participators’ location privacy, and few are done on participators’s trajectory privacy. The effective analysis on trajectories that contain spatial-temporal history information will reveal participators’s whereabouts and the relevant personal privacy. In this work, we proposed a trajectory privacy-preserving framework, named TrPF, for participatory sensing. Based on the framework, we improved the theoretical mix-zones model with considering the time factor from the perspective of graph theory to construct trajectory mix-zones model for protecting participators’ sensitive trajectory segments. In addition, we analyzed the threat models with different background knowledge and evaluated the effectiveness of our proposal on the basis of information entropy, and then compared the performance of our proposal with previous trajectory privacy protections. The analysis and simulation results demonstrated that our proposal can protect participators’ trajectories privacy effectively with lower information loss and costs than what is afforded by the other proposals.


Energy and power are two biggest concerns of today’s computing systems, including mobile devices and servers at data centers. Since 2008, we have started investigating the problem from systems point of view. We observed that software indeed causes a lot of energy in the system. Therefore, we focus on energy and power management in the software systems including both system software, e.g., OSes, and application software. The basis of power-aware design is accurate, verbose, and real-time power estimation. A better understanding of the power dissipation of a system will enable more energy saving opportunities. Despite years of research efforts on computer system power estimation, most existing approaches either do not expose sufficient information to end-users and software developers or lack the consideration of platform-dependent factors. Our solution is to design and implement a simple and efficient process-level power profiling tool to solve the problem of estimating the amount of energy consumed by each application in the system: pTop [13]. We have developed and released both the Linux and Windows version of pTop, which has been downloaded more than 500+ times and used in many groups both nationally and internationally.

Software contributes a considerable portion to the total power of a computer system [9]. Hence, it is important to quantify the power dissipation of a software component in computer systems in a fine-grained way. As the complementary yet independent project, we propose a function level power profiling model for software running on multi-core processors. Concretely, we model power dissipation in a two-level manner to reserve simplicity and accuracy using performance monitoring counters (PMCs); then, we map power dissipation to software blocks at runtime by building libraries and interfaces. we design and implement SPAN [65], a software power analyzer, to identify power behavior associated with source code. SPAN also provide APIs to support live, real time power phases information of running applications. Different from SPAN, which requires the access of source code for software power analysis, we designed and implemented Safari [66], a function-level power analysis using automatic instrumentation, for certain scenarios where the source code is not available. The experiment results show that Safari is able to produce function level profiling with limited overhead (on average 16% overhead if maximum one sample is collected for each function). It can be used to connect application activities to hardware for energy-efficient design, such as application aware power management and fine-grained scheduling. Huawei Technologies Inc. is very interested in using SPAN/Safari, and made a donation to support our research in this direction. We have implemented SPAN on both general-purpose and embedded multicore systems, and released the software. SPAN/Safari have been downloaded 80+ times since released. Intel has shown great interests to our work on software power analysis and invited one of my students to work with them. We are working on a joint project among Alibaba Group and Intel on high energy-efficient server design and
management.

In addition to software power analysis and optimization, we have also investigated multiple energy-efficient mechanisms on both mobile side and the server (data center) side. In the mobile end, we have proposed several models and tools for extending the battery life, which is one of the most important resources an end user cares about. To provide a generic view of different battery optimization techniques, we first developed a prediction model [25] that calculates how long the battery can be extended under various situations. The model takes hardware components’ information and user behavior into consideration, providing a mechanism to evaluate various energy saving methods for different users. Assuming the application’s power is relatively stable and the user behavior pattern is known, we can analyze the influence of each hardware component to the device’s battery life. For some users, if the energy efficiency of the display is doubled, the battery lifetime will increase 18.57%. From the perspective of users, the possible maximum battery lifetime can be calculated as well. For example, compared with the original 66h for users who rarely use their smartphone, we found that the battery life can be extended to 147h (more than 6 days) when we only maintain applications in the top three commonly used categories. Moreover, given a target battery discharging time, the prediction model will provide the information for how much improvement we need to achieve.

Furthermore, we designed and implemented BatteryExtender [39], which won the Best Paper Nominee Award at ACM UbiComp’14, to attack the problem of on-demand battery life extension, i.e., what users can do if they need their device to last for a specific duration in order to perform a specific task. BatteryExtender is a first user-guided power management tool that enables the reconfiguration of the device’s resources based on the workload requirement, similar to the principle of creating virtual machines in the cloud. It predicts the battery life savings based on the new configuration, in addition to predicting the impact of running applications on the battery life. Through our experimental analysis, BatteryExtender decreased the energy consumption between 10.03% and 20.21%, and in rare cases by up to 72.83%. The accuracy rate ranged between 92.37% and 99.72%.

At the server side of cloud computing, we have made significant contributions on improving resource utilization and reducing energy consumption [40, 44, 57, 71, 74]. First, we have introduced the notion of Application-Specific Energy Efficiency (ASEE) [40], which captures the correlation between the various hardware, software/application and the energy efficiency. In this study, we have witnessed 70% of ASEE improvement by changing the virtual machine size within the same node while keeping an identical load. In different cases, we witnessed up to 86% of ASEE improvement by running the same application with the same load within the same size of virtual machine but on different nodes. Second, based on ASEE, we have proposed and implemented RESCUE [74], an energy-aware scheduler for heterogeneous cloud environments. RESCUE ranks nodes within the cloud based on their ASEE respectively, then assigns the workload to the most energy efficient machine while keeping the same performance. Our approach leverages knowledge of the power consumption behavior of the underlying hardware and the characteristics of workloads in order to increase their overall energy efficiency. Our ultimate goal is to provide a scheduling mechanism that allows cloud providers to reduce the energy consumption of their data centers without needing to replace the underlying hardware, and to do so seamlessly, without impacting clients’ performance requirements.

Finally, we further observed that the failures caused by hardware, software or humans in the data center will cause another level of energy waste, where jobs have to be resubmitted and re-executed after failures. We propose to address this problem proactively by leveraging a reputation-based resource selection scheme to reduce the number of resubmissions of tasks, resulting from the failure during the course of their execution [44]. To capture the characteristics of resources, we introduce Opera, an OPEn ReputAtion model. Opera characterizes itself with two important novelties: a vector representation of the reputation and the just-in-time feature that represents the real-time system status, which, to our knowledge, has never been considered in conventional reputation systems. To demonstrate the effectiveness of Opera, we have integrated the Opera trust model into the scheduler of Hadoop. The experimental results showed that Opera enables the scheduler to select appropriate nodes which helped to reduce not only the number of re-executed tasks but also the execution time of Hadoop’s jobs under the presence of failures and heavy workload up to 59% and 32%, respectively. This improvements,
in turn, can improve the energy efficiency of the whole system and the network by 16.17% and 53.32% for the sort application respectively.

3.6 Content and Protocol Adaptation in Mobile Computing (2000-2006)

Internet has an inherent mismatch between the low-bandwidth, limited resource characteristics of mobile devices and the high-bandwidth expectations of many content-rich services. Existing applications and services cope with the above problem essentially by providing differentiated service for different networks and devices. For example, most popular news, e-mail, and stock trading services today present a different front-end for mobile users. Although adequate in some scenarios, this approach suffers from the limitation that mobile users are classified into a small number of classes and may not receive performance commensurate with the capabilities of the device or network they are using. More importantly, such an approach cannot adequately cope with dynamically changing environments where there is a big variation in available bandwidth (e.g., a user on a wireless LAN whose distance from an access point varies through time).

To address this mismatch problem between clients and servers, we have proposed Composable Adaptive Network Services (CANS) [15], an application-level infrastructure for customizing the data path between client applications and services, which focuses on three challenges: (1) efficient component composition, (2) support for legacy applications and services, and (3) support for distributed adaptation. Our first paper about CANS [15] has been published on the 3rd USENIX Symposium on Internet Technologies and Systems (USITS ’01), which has renamed to NSDI since 2004. This paper has been cited 192 times.

To address the deployment problem of CANS, we have proposed Fractal, a framework for dynamic application protocol adaptation in mobile computing [36, 37]. Fractal works entirely at the application level and has no specific requirements about underlying network topologies, connection media types, network protocols, and client hardware configurations.

It is difficult, if not impossible, to build a one-size-fit-all application or protocol which can run well in the dynamic environment. Adaptation has been considered as a general approach to address the mismatch problem between clients and servers. From the perspective of adaptation locations, some of them propose the in-network adaptation, such as CANS, Active Names, Odyssey, and Rover, which focus on how to do the adaptation step by step across an overlay path. Although the functionalities are well designed, they have not considered the deployment of chosen components (drivers in CANS) across multiple nodes in the path. This is an obstacle for the wide acceptance of these approaches. Other proposals try to perform the end-to-end adaptation, like the static content-based adaptation, which does not take the mobility of users and dynamically changing environment into consideration. From the network OSI model’s point of view, some of them work in the network layer, which adapts the TCP/IP protocol dynamically according to the changing situations on both ends. Although the results are promising, it is not able to handle the application level protocol adaptation which makes more sense for many overlay distributed applications, e.g., streaming multicast on the Internet. In this paper we propose Fractal, a dynamic application level protocol adaptation approach, which uses the mobile code technology for protocol adaptation and leverages existing content distribution networks (CDN) for protocol adaptors (PADs) (mobile codes) deployment. The idea of protocol adaptation is based on the assumption that an application protocol is composed of a series of components, also called PADs in the Fractal framework. When a protocol needs to be adapted, the application simply needs to add or remove some PADs into or from it. Before a mobile client starts an application session with the application server, it uses the proposed interactive negotiation protocol to negotiate with the adaptation proxy deployed close to the application server. The negotiation manager inside the adaptation proxy uses the proposed adaptation path search algorithm to find one or more appropriate PADs that should be used in the following communication between the client and the application server. Metadata about these PADs will be sent to the client by the adaptation proxy. The client is then able to retrieve the PADs, which are packaged into mobile code modules, from the CDN and starts the new protocol. Although a large amount of research on mobile code and CDN has been done, few studies have combined the advantage of both of them for
the protocol adaptation purpose. Based on the proposed framework, we have designed and implemented two case studies: an adaptive message encryption protocol and an adaptive communication optimization protocol. The contributions of Fractal are five-fold: (1) Proposing a general framework for dynamic application level protocol adaptation; (2) Dynamically adapting at the application protocol level; (3) Leveraging CDN edgeservers for protocol adaptor delivery; (4) Designing and implementing an adaptive message encryption protocol in the context of the Fractal framework; and (5) Proposing and implementing an adaptive communication optimization protocol in the context of the Fractal framework.

The Fractal paper has been awarded the Best Paper Award in the 19th IEEE International Parallel and Distributed Processing Symposium (IPDPS ’05), which is a premier conference in the field of parallel and distributed computing. Fractal has been very successfully applied to UbiCAS [33], a mobile Computer-Assisted Surgery system that allows surgeons to retrieve, review and interpret multimodal medical images, and to perform some critical neurosurgical procedures on heterogeneous devices from anywhere at anytime.

4 Summary

In summary, I have been working in the general area of networked distributed systems in the last 15 years, and have made significant progress which has been recognized by the research community. I plan to continue the endeavor and keep exploring the new frontiers of distributed systems research in the future, especially on sustainable computing and systems for big data, include two related directions: (1) how to develop power- and energy-efficient computer systems and applications, ranging from mobile devices to data centers; and (2) how to apply advanced computing technologies for sustainability, especially for wireless health. For the first part, we have actively collaborated with industries, such as Intel, Huawei, Alibaba Group, Beijing Genomics Institute (BGI) on systems design and optimization. For the second part, in November 2011, with Profs. Bengt Arnetz (Family Medicine) and Chin-An Tan (Mechanical Engineering), we founded the Wireless Health Initiative (http://wirelesshealth.wayne.edu) aiming to bring together researchers and health care stakeholders, including health care providers, patients, insurance, pharmaceutical and medical technology companies together with expertise in computer sciences, sensors and wireless technologies, electronics, data mining, and bioinformatics. This initiative received a strong support from the Office of Vice President for Research and the Dean of College of Engineering, we are currently in the processing of form a Center for Wireless Health at Wayne State University. From computer systems point of view, there are two big concerns in wireless health infrastructure: robust, reliable data collection and feedback infrastructure and how to transfer, store and process the big data collected from different sources. My research group has been actively developing the enabling technologies and will continue working in the area in the future.

References


[14]


