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Arizona State University
ORSPA
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| UU | UU | UU | UU | | 19b. TELEPHONE NUMBER 480-965-6218 |

# RPPR Final Report
as of 03-Apr-2019

Agency Code:

Proposal Number: 54650CS **Agreement Number: W911NF-09-1-0467**
**INVESTIGATOR(S):**

**Name:** Ph.D. Guoliang Xue xue@asu.ed
**Email:** xue@asu.edu
**Phone Number:** 4809656218
**Principal:** Y

Organization: **Arizona State University**
Address: ORSPA, Tempe, AZ 852876011
Country: USA
DUNS Number: 943360412 EIN: 860196696
**Report Date:** 24-Nov-2014 Date Received: 01-Apr-2019
**Final Report** for Period Beginning 25-Aug-2009 and Ending 24-Aug-2014
**Title:** Multi-Contrained Multi-Path Routing Algorithms
**Begin Performance Period:** 25-Aug-2009 **End Performance Period:** 24-Aug-2014
**Report Term:** 0-Other
Submitted By: Ph.D. Guoliang Xue Email: xue@asu.edu
Phone: (480) 965-6218
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**STEM Degrees:** 6 **STEM Participants:** 6

**Major Goals:** Objective
In this high-tech and network-centric era, many of our military actions require the transmission of high quality video in real time in a computer or communications networks. The objective of this project is to design effective algorithms for routing in computer networks subject to multiple constraints. Given a source node s and a destination node t, it is of great importance to compute an s—t path or a set of s—t paths such that the aggregated bandwidth of the set of paths is greater than or equal to a specified bandwidth requirement and at the same time, the longest delay of the paths is no more than a specified delay requirement.

Approach
The computer network is modeled by a graph where the vertices represent processing elements such as computers, routers, etc., and the edges represent communication links. Each link is associated with several attributes, such as bandwidth, delay, cost, or reliability. These problems are NP-complete. Therefore, it is unlikely to find polynomial time algorithms that can compute an optimal solution to the problem. The proposed approach for solving these multi-constrained multipath routing problems is to design efficient approximation algorithms. Given any given positive constant ?, it is desirable to compute, in polynomial time, a solution, that is within a factor of (1+?) of the optimal solution.

To achieve this goal, techniques from theoretical computer science and operations research are used or designed. These techniques involve (1) scaling and rounding, (2) network flows, (3) linear programming, and (4) game theory. Scaling and rounding can be used to simplify an instance of the problem without losing too much precision. Network flow algorithms are used to find an upper bound on the aggregated bandwidth between the source node and the destination node. Linear programming techniques can be used to find routing to satisfy both bandwidth requirement and delay requirement. Game theoretic techniques can be used to characterize the selfish behaviors of the users involved.

Scientific Opportunities and Barriers
Multi-constrained multipath routing is an important problem that has not been well understood. Nondeterministic link delays make the computation of a shortest path a challenging problem. The existence of multiple users competing for the limited network resources complicates the problem. Selfish behaviors of users make the problem even more challenging. However, along these challenges are opportunities to design new algorithmic techniques and to gain deeper understanding of the problems.

During the research activities of this project, we also designed novel techniques for user authentication of light-weight devices. This research has led to a US patent, in addition to high impact publications. We have also studied the selfish behavior of users in mobile systems. To this end, we pioneered the design of incentive mechanisms for mobile crowdsensing, which opens a new area of research. We have also worked on important research issues in smartgrid. Our paper on smartgrid has received 1946 citations. Please refer to the section on accomplishments.

Significance
The problems studied in this project have both defense and civilian applications. For example, one of the problems studied is to find a routing path that can transmit a large video file with guaranteed bandwidth in the network. This enables video stored at one location to be viewed at another location in real-time with a guaranteed viewing quality. Our technique on user authentication on smart devices has applications in both military and civilian environments. The techniques developed in to solve problems in one area have been used to develop theories for solving problems in other areas. Similarly, the results of the proposed research will have significant impact on developments in other disciplines as well, both in terms of research and education.

**Accomplishments:** Since the first three years of the project, we have made several significant contributions. These are summarized in the following.

(1) In a paper published in the IEEE/ACM Transactions on Networking (April 2014), “A Polynomial-Time Algorithm for Computing Disjoint Lightpath Pairs in Minimum Isolated-Failure-Immune WDM Optical Networks”, we designed a polynomial-time algorithm for computing a disjoint lightpath pair in minimum isolated-failure-immune WDM optical networks. Computing disjoint lightpath pairs in general optical networks is an NP-hard problem. In this paper, we demonstrate that minimum isolated-failure-immune WDM networks are an important class of survivable optical networks. Then we design novel algorithms by exploring the intrinsic property of this kind of networks.

(2) In a paper published in NDSS’2013 (20th Annual Network & Distributed System Security Symposium), “Unobservable Re-authentication for Smartphones”, we design a novel technique to authenticate the user of a smart device. Our technique uses the figure traces the user left on the touchscreen, and apply machine learning algorithms to decide whether the user is the owner of the device or a stranger of the device. Our work is one of the earliest work that uses machine learning techniques to solve security problems, and the earliest work to use figure traces on touch screens to study security problems. This novel work has resulted a US patent (US9996803).

(3) In a paper published in IEEE Transactions on Dependable and Secure Computing (November/December 2016), “A Proximity Authentication System for Smartphones”, we proposed novel techniques to decide whether two smart devices are close to each other. This technique is useful in both military and civilian applications. In an INFOCOM’ 2013 paper, “Efficient Anonymous Message Submission”, we proposed a method to submit online comments anonymously. This technique can find applications in electronic voting. Its journal version is published in IEEE Transactions on Dependable and Secure Computing in 2018. In two papers published in AsiaCCS’2012 (7th ACM Symposium on Information, Computer and Communications Security), we proposed identity authentication protocols and privacy techniques in online social networks.

(4) In a paper published in ACM MobiCom’2012 (ACM International Conference on Mobile Computing), “Crowdsourcing to Smartphones: Incentive Mechanism Design for Mobile Phone Sensing”, we proposed incentive mechanisms for mobile crowdsourcing. This pioneering work has led to active research in this area. So far, this paper has been cited for more than 700 times. Its journal version has been published in IEEE/ACM Transactions on Networking (June 2016). We also published a sequence of improved works along this line, in INFOCOM’2014, INFOCOM’2015, and IEEE Internet of Things Journal (December 2015).

(5) We have also worked on important research issues in smart grids. In a survey paper published in the IEEE Communications Survey and Tutorials (Fourth Quarter, 2012), “Smart Grid – The New and Improved Power Grid: A Survey”, we give a comprehensive survey of the topic and identified important research issues. This paper has since become “the survey” paper on this topic. So far, this paper has been cited for 1946 times. In a follow-up paper, published in the IEEE Transactions on Smart Grid, we proposed a cloud computing based method to reduce the cost of information management in the smart grid.

Throughout the whole project period, the research has resulted in a total of
1 US Patent,

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19 Journal Papers,
22 Refereed Conference Papers.

4 PhD students (including one female), 1 Master student (female, African American), and 1 undergraduate student (Hispanic) are graduated.

**Training Opportunities:** Graduate students get the opportunity to learn state of the art techniques in information technology. Four PhD students, one Master students, and one undergraduate students are graduated, joining the work force in both academia and industry.

Dejun Yang (PhD, 2013) joined Colorado State University as the Ben L. Fryrear Assistant Professor of Computer Science.

Xi Fang (PhD, 2013) joined Microsoft after graduation.

Lingjun Li (PhD, 2014) joined Google after graduation.

Xinxin Zhao (PhD, 2015) joined Hermes Microvision after graduation.

Margaret Todd (MS, 2016) joined Sandia National Lab aftger graduation.

Gabriel Silva (BS, 2013) joined Microsoft after graduation.

Xiang Zhang (PhD candidate) joined Facebook in 2018.

Ruozhou Yu (PhD candidate) accepted an offer from North Carolina State University as a Tenure-Track Assistant Professor in Computer Science, starting in fall 2019.

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**Results Dissemination:** Eight journal papers and seven refereed conference papers are published during this report period. In addition, this research has resulted a US patent. These are listed in the following:

[01] Guoliang Xue, Ravi Gottapu, Xi Fang, Dejun Yang, Krishnaiyan Thulasiraman, "A Polynomial-Time Algorithm for Computing Disjoint Lightpath Pairs in Minimum Isolated-Failure-Immune WDM Optical Networks", IEEE/ACM Transactions on Networking, Vol. 22 (2014), pp. 470-483.

[02] Lingjun Li, Xinxin Zhao, Guoliang Xue, "Unobservable Re-authentication for Smartphones", NDSS'2013. San Diego, USA, 24-27 February 2013.

[03] Lingjun Li, Xinxin Zhao, Guoliang Xue, "Systems and Methods for Authenticating a User Through An Unobservable Re-authentication System", United States Patent, US9996803, June 12, 2018.

[04] Lingjun Li, Xinxin ZHao, Guoliang Xue, "A Proximity AUthentication System for Smartphones", IEEE Transactions on Dependable and Secure Computing, Vol. 13 (2016), pp. 605-616.

[05] Xinxin Zhao, Lingjun Li, Guoliang Xue, Gabriel Silva, "Efficient Anonymous Message Submission", IEEE INFOCOM'2012, pp. 2228-2236.

[06] Xinxin Zhao, Lingjun Li, Guoliang Xue, Gail-Joon Ahn, "Efficient Anonymous Message Submission", IEEE Transactions on Dependable and Secure Computing, Vol. 15 (2018), pp. 217-230.

[07] Lingjun Li, Xinxin Zhao, Guoliang Xue, "An Identity Authentication Protocol in Online Social Networks", AsiaCCS,2012, Seoul, Korea, May 2-4, 2012.

[08] Xinxin Zhao, Lingjun Li, Guoliang Xue, "Keeping Identity Secret in Online Social Networks", AsiaCCS,2012, Seoul, Korea, May 2-4, 2012.

[09] Dejun Yang, Guoliang Xue, Xi Fang, Jian Tang, "Crowdsourcing to Smartphones: Incentive Mechanism Design for Mobile Phone Sensing", ACM MobiCom'2012, pp. 173-184, Istanbul, Turkey, August 22-26, 2012.

[10] Dejun Yang, Guoliang Xue, Xi Fang, Jian Tang, "Incentive Mechanisms for Crowdsensing: Crowdsourcing With Smartphones", IEEE/ACM Transactions on Networking, Vol. 24 (2016), pp. 1732-1744.

[11] Dejun Yang, Xiang Zhang, Guoliang Xue, "PROMISE: A Framework for Truthful and Profit Maximizing Spectrum Double Auctions", IEEE INFOCOM'2014, Toronto, Canada, April 27-May 2, 2014.

[12] Xiang Zhang, Guoliang Xue, Ruozhou Yu, Dejun Yang, Jian Tang, "Truthful Incentive Mechanisms for Crowdsourcing", IEEE INFOCOM'2014, Hong Kong, April 26-May 1, 2015.

[13] Xiang Zhang, Guoliang Xue, Ruozhou Yu, Dejun Yang, Jian Tang, "Keep Your Promise: Mechanism Design Against Free-Riding and False-Reporting in Crowdsourcing", IEEE Internet of Things Journal, Vol. 2 (2015), pp. 562-572.

[14] Xi Fang, Satyajayant Misra, Guoliang Xue, Dejun Yang, "Smart Grid – The New and Improved Power Grid: A Survey", IEEE Communications Survey & Tutorials, Vol. 14 (2012), pp. 944-980.

[15] Xi Fang, Dejun Yang, Guoliang Xue, "Evolving Smart Grid Information Management Cloudward: A Cloud Optimization Perspective", IEEE Transactions on Smart Grid, Vol. 4 (2013), pp. 111-119.

[16] Dejun Yang, Guoliang Xue, Jin Zhang, Andrea Richa, Xi Fang, "Coping with a Smart Jammer in Wireless Networks: A Stackelberg Game Approach", IEEE Transactions on Wireless Communications, Vol. 12 (2013), pp. 4038-4047.

**Honors and Awards:** The PI, Guoliang Xue, was elevated to IEEE Fellow in 2011.

The PI, Guoliang Xue, was elected as Vice-President of the IEEE Communications Society in charge of conferences for the term January 2016-December 2017.

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**Protocol Activity Status:**

**Technology Transfer:** The research resulted in a US patent:

Lingjun Li, Xinxin Zhao, Guoliang Xue, "Systems and Methods for Authenticating a User Through An Unobservable Re-authentication System", United States Patent, US9996803, June 12, 2018.

**PARTICIPANTS:**

**Participant Type:** PD/PI
**Participant:** Guoliang Xue
**Person Months Worked:** 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

**Participant Type:** Graduate Student (research assistant)
**Participant:** Xiang Zhang
**Person Months Worked:** 6.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

**ARTICLES:**

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Publication Location:
**Article Title:** Computing a Most Probable Delay Constrained Path: NP-Hardness and Approximation Schemes
**Authors:**
**Keywords:** Delay constrained path selection, computational complexity,approximation schemes
**Abstract:** Delay constrained path selection is concerned with finding a source-to-destination path so that the delay of the path is within a given delay bound. When the network is modeled by a directed graph where the delay of a link is a random variable with a known mean and a known variance, the problem becomes that of computing a most probable delay constrained path. In this paper, we present a comprehensive theoretical study of this problem. First, we prove that the problem is NP-hard. Next, for the case where there exists a source-to-destination path with a delay mean no more than the given delay bound, we present a fully polynomial time approximation scheme. In other words, for any given constant epsilon such that 0 < epsilon < 1, our algorithm computes a path whose probability of satisfying the delay constraint is at least (1-epsilon) times the probability that the optimal path satisfies the delay constraint, with a time complexity bounded by a polynomial in the number of network nodes
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Volume: 0 Issue: 0 First Page #: 0
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Publication Location:
**Article Title:** MAP: Multi-Constrained Anypath Routing in Wireless Mesh Networks
**Authors:**
**Keywords:** Wireless mesh networks, anypath routing, multipleconstraints, provably good approximation algorithms.
**Abstract:** Anypath routing has been proposed to improve the performance of unreliable wireless networks by exploiting the spatial diversity and broadcast nature of the wireless medium. Previous studies on anypath routing have been concentrated on finding an anypath which optimizes a single quality of service (QoS) parameter. In this paper, we study anypath routing subject to multiple constraints. We first prove that the problem is NP-hard when the number of constraints is larger than one. We then present a polynomial time K-approximation algorithm MAP (Multi-constrained AnyPath), where K denotes the number of constraints. Our algorithm is as simple as Dijkstra's shortest path algorithm. Therefore it is suitable for implementation in wireless routing protocols.
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Volume: 30 Issue: 2 First Page #: 245
Date Submitted: Date Published:
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**Article Title:** HERA: An Optimal Relay Assignment Scheme for Cooperative Networks
**Authors:**
**Keywords:** Relay Assignment, Cooperative Communication, Truthful Auction
**Abstract:** Exploiting the nature of broadcast and the relaying capability of wireless devices, cooperative communication is becoming a promising technology to increase the channel capacity in wireless networks. In cooperative communication, the scheme for assigning relay nodes to users plays a critical role in the resulting channel capacity. A significant challenge is how to make the scheme robust to selfish and cheating behavior of users while guaranteeing the social optimal system capacity. In this paper, we design an integrated optimal relay assignment scheme called HERA for cooperative networks. To avoid system performance degradation due to the selfish relay selections by the source nodes, we propose a payment mechanism for charging the source nodes to induce them to converge to the optimal assignment. To prevent relay nodes from manipulating the relay assignment by reporting transmission power untruthfully, we propose a payment mechanism to pay them for providing relaying service. We also s
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**Article Title:** A polynomial time algorithm for computing disjoint lightpath pairs in minimum isolated failure immune WDM optical networks
**Authors:** Guoliang Xue, Ravi Gottapu, Xi Fang, Dejun Yang, Krishnaiyan Thulasiraman
**Keywords:** Link Disjoint Lightpaths, Survivability, Polynomial Time Algorithm
**Abstract:** A fundamental problem in survivable routing in WDM optical networks is the computation of a pair of linkdisjoint (or node-disjoint) lightpaths connecting a given pair of source and destination nodes, subject to the wavelength continuity constraint. However, this problem is NP-hard when the underlying network topology is a general mesh network. As a result, heuristic algorithms and ILP formulations for solving this problem have been proposed. In this paper, we advocate the use of 2-edge connected (or 2-node connected) subgraphs of minimum isolated failure immune networks as the underlying topology for WDM optical networks. We present a polynomial time algorithm for computing a pair of link-disjoint lightpaths with shortest total length in such networks, whenever such a pair exists. In particular, the running time of our algorithm is O(nW^2), where n is the number of nodes in the network, and W is the number of wavelengths per link. Numerical results are presented to demonstrate the effe
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**Article Title:** Smart Grid--The New and Improved Power Grid: A Survey
**Authors:**
**Keywords:** Smart grid, power grid, survey, energy, information,communications, management, protection, security, privacy.
**Abstract:** The Smart Grid, regarded as the next generation power grid, uses two-way flows of electricity and information to create a widely distributed automated energy delivery network. In this article, we survey the literature till 2011 on the enabling technologies for the Smart Grid. We explore three major systems, namely the smart infrastructure system, the smart management system, and the smart protection system. We also propose possible future directions in each system. Specifically, for the smart infrastructure system, we explore the smart energy subsystem, the smart information subsystem, and the smart communication subsystem. For the smart management system, we explore various management objectives, such as improving energy efficiency, profiling demand, maximizing utility, reducing cost, and controlling emission. We also explore various management methods to achieve these objectives. For the smart protection system, we explore various failure protection mechanisms which improve the relia
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**Article Title:** Pathbook: Cross-layer optimization for full-duplex wireless networks
**Authors:**
**Keywords:** Full-duplex wireless networks?Full-duplex broadcast MAC?Multipath routing?Cross-layer optimization?Network utilization
**Abstract:** Recently, Choi et al. designed the first practical full-duplex wireless system, which challenges the basic assumption in wireless communications that a radio cannot transmit and receive on the same frequency at the same time. In this paper, we study cross-layer optimization for full-duplex wireless networks, comprehensively considering various resource and social constraints. We focus on (1) the problem of allocating resources to maximize the total profit of multiple users subject to node constraints and (2) the problem of allocating resources to minimize the network power consumption subject to user rate demands and node constraints. We formulate these problems as convex programming systems. By combining Lagrangian decomposition and subgradient methods, we design distributed iterative algorithms to solve these problems, which compute the optimized user information flow (i.e. user behavior) for the network layer and the optimized node broadcast rate (i.e. node behavior) for the MAC lay
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**Article Title:** A Polynomial-Time Algorithm for Computing Disjoint Lightpath Pairs in Minimum Isolated-Failure-Immune WDM Optical Networks
**Authors:**
**Keywords:** Disjoint lightpath pairs, minimum isolatedfailure immune networks, partial 2-trees, wavelength divisionmultiplexing (WDM) optical network.
**Abstract:** A fundamental problem in survivable routing in wavelength division multiplexing (WDM) optical networks is the computation of a pair of link-disjoint (or node-disjoint) lightpaths connecting a source with a destination, subject to the wavelength continuity constraint. However, this problem is NP-hard when the underlying network topology is a general mesh network. As a result, heuristic algorithms and integer linear programming (ILP) formulations for solving this problem have been proposed. In this paper, we advocate the use of 2-edge connected (or 2-node connected) subgraphs of minimum isolated failure immune networks as the underlying topology for WDM optical networks. We present a polynomial-time algorithm for computing a pair of link-disjoint lightpaths with shortest total length in such networks. The running time of our algorithm is , where is the number of nodes, and is the number of wavelengths per link. Numerical results are presented to demonstrate the effectiveness and scalabil
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**Article Title:** A Game-Theoretic Approach to Stable Routing in Max-Min Fair Networks
**Authors:**
**Keywords:** Fair queueing, Nash equilibrium (NE), noncooperativegame, price of anarchy, stable routing.
**Abstract:** In this paper, we present a game-theoretic study of the problem of routing in networks with max-min fair congestion control at the link level. The problem is formulated as a noncooperative game, in which each user aims to maximize its own bandwidth by selecting its routing path. We first prove the existence of Nash equilibria. This is important, because at a Nash equilibrium (NE), no user has any incentive to change its routing strategy—leading to a stable state. In addition, we investigate how the selfish behavior of users may affect the performance of the network as a whole. We next introduce a novel concept of observed available bandwidth on each link. It allows a user to find a path with maximum bandwidth under max-min fair congestion control in polynomial time, when paths of other users are fixed. We then present a game-based algorithm to compute an NE and prove that by following the natural game course, the network converges to an NE. Extensive simulations show that the algorithm
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**Article Title:** PROMISE: A Framework for Truthful and ProfitMaximizing Spectrum Double Auctions
**Authors:** Dejun Yang, Xiang Zhang, Guoliang Xue
**Keywords:** Cognitive radio and software defined radio; Network economics and pricing
**Abstract:** Auctions provide a platform for licensed spectrum users to trade their underutilized spectrum with unlicensed users. Existing spectrum auctions either do not apply to the scenarios where multiple sellers and buyers both make offers, or assume the knowledge of the users' valuation distribution for maximizing the profit of the auction. To fill this void, we design PROMISE, a framework for spectrum double auctions, which jointly considers spectrum reusability, truthfulness, and profit maximization without the distribution knowledge. We propose a novel technique, called cross extraction, to compute the bid representing a group of secondary users, who can share a common channel. We prove that PROMISE is computationally efficient, individual-rational, and truthful. In addition, PROMISE is guaranteed to achieve an approximate profit of the optimal auction.
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**Article Title:** Unobservable Re-authentication for Smartphones
**Authors:** Lingjun Li, Xinxin Zhao, Guoliang Xue
**Keywords:** user authentication
**Abstract:** The widespread usage of smartphones gives rise to new security and privacy concerns. Smartphones are becoming a personal entrance to networks, and may store private information. Due to its small size, a smartphone could be easily taken away and used by an attacker. Using a victim's smartphone, the attacker can launch an impersonation attack, which threatens the security of current networks, especially online social networks. Therefore, it is necessary to design a mechanism for smartphones to re-authenticate the current user's identity and alert the owner when necessary. Such a mechanism can help to inhibit smartphone theft and safeguard the information stored in smartphones. In this paper, we propose a novel biometric-based system to achieve continuous and unobservable re-authentication for smartphones. The system uses a classifier to learn the owner's finger movement patterns and checks the current user's finger movement patterns against the owner's.
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**Article Title:** A Proximity Authentication System for Smartphones
**Authors:** Lingjun Li, Xinxin Zhao, Guoliang Xue
**Keywords:** Jamming, Stackelberg Game
**Abstract:** Jamming defense is an important yet challenging problem. In this paper, we study the jamming defense problem in the presence of a smart jammer, who can quickly learn the transmission power of the user and adaptively adjust its transmission power to maximize the damaging effect. We consider both the single-channel model and the multi-channel model. By modeling the problem as a Stackelberg game, we compute the optimal transmission power for the user to maximize its utility, in the presence of a smart jammer. For the single channel model, we prove the existence and uniqueness of the Stackelberg Equilibrium (SE) by giving closed-form expressions for the SE strategies of both the user and the player. For the multi-channel model, we prove the existence of the SE. We design algorithms for computing the jammer's best response strategy and approximating the user's optimal strategy. Finally, we validate our theoretical analysis through extensive simulations.
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Publication Location:
**Article Title:** Efficient Anonymous Message Submission
**Authors:** Xinxin Zhao, Lingjun Li, Guoliang Xue, Gail-Joon Ahn
**Keywords:** Group messaging submission, secret sharing scheme, accountablility, anonymity, identity protection
**Abstract:** Anonymity is important for online message collection. Existing solutions let each member blindly shuffle the submitted messages. In the end, the message sender's identities are protected since no one knows the message submission order. These approaches cannot efficiently handle groups of large size. In this paper, we propose an efficient anonymous message submission protocol aimed at a practical group size. Our protocol is based on a secret sharing scheme and a symmetric key cryptosystem. We propose a novel method to aggregate members' messages into a message vector such that a group member knows only his own position in the submission sequence. The protocol is accountable for capturing malicious members breaking the protocol execution. We provide a theoretical proof showing that our protocol is anonymous under malicious attacks. We also discuss our simulation results to demonstrate the efficiency of our protocol.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE/ACM Transactions on Networking
Publication Identifier Type: DOI Publication Identifier: 10.1109/TNET.2015.2421897
Volume: 24 Issue: 3 First Page #: 1732
Date Submitted: 4/1/19 12:00AM Date Published: 6/1/16 7:00AM
Publication Location:
**Article Title:** Incentive Mechanisms for Crowdsensing: Crowdsourcing With Smartphones
**Authors:** Dejun Yang, Guoliang Xue, Xi Fang, Jian Tang
**Keywords:** Crowdsensing, crowdsourcing, incentive mechanism, Stackelberg game.
**Abstract:** Crowdsensing is a new paradigm which takes advantage of the pervasive smartphones to sense, collect, and analyze data. We consider two system models: the crowdsourcer-centric model where the crowdsourcer provides a reward shared by participating users, and the user-centric model where users have more control over the payment they will receive. For the crowdsourcer-centric model, we design an incentive mechanism using a Stackelberg game, where the crowdsourcer is the leader while the users are the followers. We show how to compute the unique Stackelberg Equilibrium, at which the utility of the crowdsourcer is maximized, and none of the users can improve its utility by unilaterally deviating from its current strategy. For the user-centric model, we design an auction-based incentive mechanism, which is computationally efficient, individually rational, profitable, and truthful.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
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**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Internet of Things Journal
Publication Identifier Type: DOI Publication Identifier: 10.1109/JIOT.2015.2441031
Volume: 2 Issue: 6 First Page #: 562
Date Submitted: 4/1/19 12:00AM Date Published: 12/1/15 7:00AM
Publication Location:
**Article Title:** Keep Your Promise: Mechanism Design Against Free-Riding and False-Reporting in Crowdsourcing
**Authors:** Xiang Zhang, Guoliang Xue, Ruozhou Yu, Dejun Yang, Jian Tang
**Keywords:** Crowdsourcing, false-reporting, free-riding, game theory, incentive mechanisms
**Abstract:** Crowdsourcing is an emerging paradigm where users can have their tasks completed by paying fees, or receive rewards for providing service. A critical problem that arises in current crowdsourcing mechanisms is how to ensure that users pay or receive what they deserve. Free-riding and false-reporting may make the system vulnerable to dishonest users. In this paper, we design schemes to tackle these problems, so that each individual in the system is better off being honest and each provider prefers completing the assigned task.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
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**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Transactions on Smart Grid
Publication Identifier Type: DOI Publication Identifier: 10.1109/TSG.2012.2230198
Volume: 4 Issue: 1 First Page #: 111
Date Submitted: 4/1/19 12:00AM Date Published: 3/1/13 12:00AM
Publication Location:
**Article Title:** Evolving Smart Grid Information Management Cloudward: A Cloud Optimization Perspective
**Authors:** Xi Fang, Dejun Yang, Guoliang Xue
**Keywords:** Cloud computing, information management, optimization, smart grid
**Abstract:** Smart grid (SG) is a power system with advanced communication and information technologies integrated and leveraged. In this paper, we study an optimization problem of leveraging the cloud domain to reduce the cost of information management in the SG. We propose a cloud-based SG information management model and present a cloud and network resource optimization framework to solve the cost reduction problem in cloud-based SG information storage and computation.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Transactions on Wireless Communications
Publication Identifier Type: DOI Publication Identifier: 10.1109/TWC.2013.071913121570
Volume: 12 Issue: 8 First Page #: 4038
Date Submitted: 4/1/19 12:00AM Date Published: 8/1/13 7:00AM
Publication Location:
**Article Title:** Coping with a Smart Jammer in Wireless Networks: A Stackelberg Game Approach
**Authors:** Dejun Yang, Guoliang Xue, Jin Zhang, Andrea Richa, Xi Fang
**Keywords:** Jamming, Stackelberg Game
**Abstract:** Jamming defense is an important yet challenging problem. In this paper, we study the jamming defense problem in the presence of a smart jammer, who can quickly learn the transmission power of the user and adaptively adjust its transmission power to maximize the damaging effect. We consider both the single-channel model and the multi-channel model. By modeling the problem as a Stackelberg game, we compute the optimal transmission power for the user to maximize its utility, in the presence of a smart jammer. For the single-channel model, we prove the existence and uniqueness of the Stackelberg Equilibrium (SE) by giving closed-form expressions for the SE strategies of both the user and the player. For the multi-channel model, we prove the existence of the SE. We design algorithms for computing the jammer's best response strategy and approximating the user's optimal strategy. Finally, we validate our theoretical analysis through extensive simulations.
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Acknowledged Federal Support: **Y**

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**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Transactions on Vehicular Technology
Publication Identifier Type: DOI Publication Identifier: 10.1109/TVT.2012.2214072
Volume: 62 Issue: 2 First Page #: 783
Date Submitted: 4/1/19 12:00AM Date Published: 2/1/13 7:00AM
Publication Location:
**Article Title:** Taming Wheel of Fortune in the Air: An Algorithmic Framework for Channel Selection Strategy in Cognitive Radio Networks
**Authors:** Xi Fang, Dejun Yang, Guoliang Xue
**Keywords:** Channel selection, cognitive radio, distributed algorithm, multi-armed bandit problem, online machine learning
**Abstract:** Cognitive radio (CR) has been proposed to improve spectrum efficiency by taking advantage of the vacancies in primary channels. Since the frequency range of operation is very wide in a CR network (CRN) and CRs cannot scan all the channels simultaneously, one of the fundamental tasks for a CR is the channel selection strategy, which directly impacts its performance. We present a distributed polynomial time algorithmic framework for computing channel strategies in a CRN with no assumption on the distribution followed by the primary users' channel occupancy. For a secondary user (SU), the upper bound on the gap between the expected profit obtained at each time slot by using the global optimal strategy and the expected profit by using our algorithm is guaranteed to be arbitrarily small when the time horizon is sufficiently large. We also prove an upper bound on the gap between the expected profit by using any strategy sequence and the expected profit by using our strategy sequence.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Wireless Communications
Publication Identifier Type: DOI Publication Identifier: 10.1109/MWC.2012.6189412
Volume: 19 Issue: 2 First Page #: 44
Date Submitted: 4/1/19 12:00AM Date Published: 4/1/12 12:00AM
Publication Location:
**Article Title:** Game theory in cooperative communications
**Authors:** Dejun Yang, Xi Fang, Guoliang Xue
**Keywords:** Game theory, cooperative communications
**Abstract:** Cooperative communication has great potential to improve the wireless channel capacity by exploiting the antennas on wireless devices for spatial diversity. However, applications of cooperative communication are barely seen in reality. A main obstacle blocking its wide application is the lack of incentives for wireless nodes to participate in cooperative communication. We first survey the existing game theoretic solutions for providing cooperation incentives in cooperative communications. We then discuss the challenges in applying game theory to cooperative communications.
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**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Transactions on Mobile Computing
Publication Identifier Type: DOI Publication Identifier: 10.1109/TMC.2011.126
Volume: 11 Issue: 8 First Page #: 1399
Date Submitted: 4/1/19 12:00AM Date Published: 8/1/12 12:00AM
Publication Location:
**Article Title:** Two-Tiered Constrained Relay Node Placement in Wireless Sensor Networks: Computational Complexity and Efficient Approximations
**Authors:** Dejun Yang, Satyajayant Misra, Xi Fang, Guoliang Xue, Junshan Zhang
**Keywords:** Relay node placement, wireless sensor networks, connectivity and survivability
**Abstract:** In wireless sensor networks, relay node placement has been proposed to improve energy efficiency. To meet the connectivity requirement, we study the connected single-cover problem where each sensor node is covered by a base station or a relay node (to which the sensor node can transmit data), and the relay nodes form a connected network with the base stations. To meet the survivability requirement, we study the 2-connected double-cover problem where each sensor node is covered by two base stations or relay nodes, and the relay nodes form a 2-connected network with the base stations. We study these problems under the assumption that R >= 2r > 0, where R and r are the communication ranges of the relay nodes and the sensor nodes, respectively. We investigate the corresponding computational complexities, and propose novel polynomial time approximation algorithms for these problems.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
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**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Network
Publication Identifier Type: DOI Publication Identifier: 10.1109/MNET.2012.6246750
Volume: 26 Issue: 4 First Page #: 32
Date Submitted: 4/1/19 12:00AM Date Published:
Publication Location:
**Article Title:** Managing smart grid information in the cloud: opportunities, model, and applications
**Authors:** Xi Fang, Satyajayant Misra, Guoliang Xue, Dejun Yang
**Keywords:** Smart grids, cloud computing
**Abstract:** Smart grid (SG), regarded as the next-generation electric grid, will use advanced power, communication, and information technologies to create an automated, intelligent, and widely distributed energy delivery network. In this article, we explore how cloud computing (CC), a next-generation computing paradigm, can be used for information management of the SG and present a novel SG information management paradigm, called Cloud Service-Based SG Information Management (CSSGIM). We analyze the benefits and opportunities from the perspectives of both the SG and CC domains. We further propose a model for CSSGIM and present four motivating applications.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

**Publication Type:** Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
**Journal:** IEEE Transactions on Intelligent Transportation Systems
Publication Identifier Type: DOI Publication Identifier: 10.1109/TITS.2011.2156790
Volume: 12 Issue: 3 First Page #: 736
Date Submitted: 4/1/19 12:00AM Date Published: 9/1/11 7:00AM
Publication Location:
**Article Title:** PACP: An Efficient Pseudonymous Authentication-Based Conditional Privacy Protocol for VANETs
**Authors:** Dijiang Huang, Satyajayant Misra, Mayank Verma, Guoliang Xue
**Keywords:** Conditional anonymity, pseudonym, vehicular ad hoc networks (VANETs)
**Abstract:** In this paper, we propose a new privacy preservation scheme, named pseudonymous authentication-based conditional privacy (PACP), which allows vehicles in a vehicular ad hoc network (VANET) to use pseudonyms instead of their true identity to obtain provably good privacy. In our scheme, vehicles interact with roadside units to help them generate pseudonyms for anonymous communication. In our setup, the pseudonyms are only known to the vehicles but have no other entities in the network. In addition, our scheme provides an efficient revocation mechanism that allows vehicles to be identified and revoked from the network if needed. Thus, we provide conditional privacy to the vehicles in the system, that is, the vehicles will be anonymous in the network until they are revoked, at which point, they cease to be anonymous.
**Distribution Statement:** 1-Approved for public release; distribution is unlimited.
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**CONFERENCE PAPERS:**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** ACM International Conference on Mobile Computing and Networking
Date Received: 01-Apr-2019 Conference Date: 22-Aug-2012 Date Published:
Conference Location: Istanbul, Turkey
**Paper Title:** Crowdsourcing to Smartphones: Incentive Mechanism Design for Mobile Sensing
**Authors:** Dejun Yang, Guoliang Xue, Xi Fang, Jian Tang
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** 2010 18th IEEE International Conference on Network Protocols (ICNP)
Date Received: 01-Apr-2019 Conference Date: 06-Oct-2010 Date Published:
Conference Location: Kyoto, Japan
**Paper Title:** Routing in max-min fair networks: A game theoretic approach
**Authors:** Dejun Yang, Guoliang Xue, Xi Fang, Satyajayant Misra, Jin Zhang
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE International Conference on Communications
Date Received: 01-Apr-2019 Conference Date: 11-Jun-2012 Date Published:
Conference Location: Ottawa, Canada
**Paper Title:** Truthful Auction for Cooperative Communications with Revenue Maximization
**Authors:** Dejun Yang, Xi Fang, Guoliang Xue
Acknowledged Federal Support: **Y**

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**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** 2011 IEEE 8th International Conference on Mobile Ad-Hoc and Sensor Systems (MASS)
Date Received: 01-Apr-2019 Conference Date: 17-Oct-2011 Date Published:
Conference Location: Valencia, Spain
**Paper Title:** Distributed Algorithms for Multipath Routing in Full-Duplex Wireless Networks
**Authors:** Xi Fang, Dejun Yang, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** NDSS'2013: Network and Distributed System Security Symposium
Date Received: 01-Apr-2019 Conference Date: 26-Feb-2013 Date Published:
Conference Location: San Diego, USA
**Paper Title:** Unobservable Re-authentication for Smartphones
**Authors:** Lingjun Li, Xinxin Zhao, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2012 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 25-Mar-2012 Date Published:
Conference Location: Orlando, FL, USA
**Paper Title:** Efficient anonymous message submission
**Authors:** Xinxin Zhao, Lingjun Li, Guoliang Xue, and Gabriel Silva
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** the 7th ACM Symposium
Date Received: 01-Apr-2019 Conference Date: 02-May-2012 Date Published:
Conference Location: Seoul, Korea
**Paper Title:** An identity authentication protocol in online social networks
**Authors:** Lingjun Li, Xinxin Zhao, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** the 7th ACM Symposium
Date Received: 01-Apr-2019 Conference Date: 02-May-2012 Date Published:
Conference Location: Seoul, Korea
**Paper Title:** Keeping identity secret in online social networks
**Authors:** Xinxin Zhao, Lingjun Li, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2015 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 26-Apr-2015 Date Published:
Conference Location: Kowloon, Hong Kong
**Paper Title:** Truthful incentive mechanisms for crowdsourcing
**Authors:** Xiang Zhang, Guoliang Xue, Ruozhou Yu, Dejun Yang, Jian Tang
Acknowledged Federal Support: **Y**

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**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** GLOBECOM 2014 - 2014 IEEE Global Communications Conference
Date Received: 01-Apr-2019 Conference Date: 08-Dec-2014 Date Published:
Conference Location: Austin, TX, USA
**Paper Title:** An efficient privacy preserving location based service system
**Authors:** Xinxin Zhao, Huiji Gao, Lingjun Li, Huan Liu, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** GLOBECOM 2014 - 2014 IEEE Global Communications Conference
Date Received: 01-Apr-2019 Conference Date: 08-Dec-2014 Date Published:
Conference Location: Austin, TX, USA
**Paper Title:** You better be honest: Discouraging free-riding and false-reporting in mobile crowdsourcing
**Authors:** Xiang Zhang, Guoliang Xue, Ruozhou Yu, Dejun Yang, Jian Tang
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2013 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 14-Apr-2013 Date Published:
Conference Location: Turin, Italy
**Paper Title:** Checking in without worries: Location privacy in location based social networks
**Authors:** Xinxin Zhao, Lingjun Li, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2013 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 14-Apr-2013 Date Published:
Conference Location: Turin, Italy
**Paper Title:** Truthful incentive mechanisms for k-anonymity location privacy
**Authors:** Dejun Yang, Xi Fang, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** the 8th ACM SIGSAC symposium
Date Received: 01-Apr-2019 Conference Date: 08-May-2013 Date Published:
Conference Location: Hangzhou, China
**Paper Title:** Secure cloud-assisted location based reminder
**Authors:** Xinxin Zhao, Lingjun Li, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2012 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 25-Mar-2012 Date Published:
Conference Location: Orlando, FL, USA
**Paper Title:** DEAR: Delay-bounded Energy-constrained Adaptive Routing in wireless sensor networks
**Authors:** Shi Bai, Weiyi Zhang, Guoliang Xue, Jian Tang, Chonggang Wang
Acknowledged Federal Support: **Y**

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**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2012 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 25-Mar-2012 Date Published:
Conference Location: Orlando, FL, USA
**Paper Title:** Strategizing surveillance for resource-constrained event monitoring
**Authors:** Xi Fang, Dejun Yang, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2012 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 25-Mar-2012 Date Published:
Conference Location: Orlando, FL, USA
**Paper Title:** Resource allocation in load-constrained multihopwireless networks
**Authors:** Xi Fang, Dejun Yang, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** GLOBECOM 2012 - 2012 IEEE Global Communications Conference
Date Received: 01-Apr-2019 Conference Date: 03-Dec-2012 Date Published:
Conference Location: Anaheim, CA, USA
**Paper Title:** Searching in the dark: A framework for authenticating unknown users in online social networks
**Authors:** Lingjun Li, Xinxin Zhao, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** GLOBECOM 2012 - 2012 IEEE Global Communications Conference
Date Received: 01-Apr-2019 Conference Date: 03-Dec-2012 Date Published:
Conference Location: Anaheim, CA, USA
**Paper Title:** Optimal transmission power control in the presence of a smart jammer
**Authors:** Dejun Yang, Jin Zhang, Xi Fang, Andrea Richa, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2011 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 10-Apr-2011 Date Published:
Conference Location: Shanghai, China
**Paper Title:** DARP: Distance-aware relay placement in WiMAX mesh networks
**Authors:** Weiyi Zhang, Shi Bai, Guoliang Xue, Jian Tang, Chonggang Wang
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2011 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 10-Apr-2011 Date Published:
Conference Location: Shanghai, China
**Paper Title:** ESPN: Efficient server placement in probabilistic networks with budget constraint
**Authors:** Dejun Yang, Xi Fang, Guoliang Xue
Acknowledged Federal Support: **Y**

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**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** IEEE INFOCOM 2011 - IEEE Conference on Computer Communications
Date Received: 01-Apr-2019 Conference Date: 10-Apr-2011 Date Published:
Conference Location: Shanghai, China
**Paper Title:** Consort: Node-Constrained Opportunistic Routing in wireless mesh networks
**Authors:** Xi Fang, Dejun Yang, Guoliang Xue
Acknowledged Federal Support: **Y**

**Publication Type:** Conference Paper or Presentation **Publication Status:** 1-Published
**Conference Name:** ICC 2013 - 2013 IEEE International Conference on Communications
Date Received: 01-Apr-2019 Conference Date: 09-Jun-2013 Date Published:
Conference Location: Budapest, Hungary
**Paper Title:** A lightweight system to authenticate smartphones in the near field without NFC chips
**Authors:** Lingjun Li, Xinxin Zhao, Guoliang Xue
Acknowledged Federal Support: **Y**

**PATENTS:**

**Intellectual Property Type:** Patent Date Received: **01-Apr-2019**
**Patent Title:** Systems and Methods for Authenticating a User through an Unobservable Re-authentication System
**Patent Abstract:** Systems and methods for an unobservable user authentication system for smartphones are disc
**Patent Number:** US 9996803 B2
Patent Country: USA
Application Date: 03-Sep-2014 Application Status: 3
Date Issued: 12-Jun-2018

Nothing to report in the uploaded pdf (see accomplishments)