Xingran Chen

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Research Fields

Research Interests: My research interests are in the intersection of Information Theory and Networks, with focus on

- Learning for Wireless Networks
- Information Freshness
- Resource Allocation and Network Economics

Education

Ph.D. in **Information and Decision Systems** 2018 - present
University of Pennsylvania Philadelphia, PA
Department of Electrical and Systems Engineering GPA: 3.94/4.0
Advisor: Prof. Shirin Saeedi Bidokhti
I work closely with Prof Saswati Sarkar and Prof Hamed Hassani.

M.A. in **Applied Mathematics and Computational Science** 2016 - 2018
University of Pennsylvania Philadelphia, PA
Applied Mathematics and Computational Science Program GPA: 4.0/4.0
Master Thesis Advisor: Prof. Saswati Sarkar

M.S. in **Operations Research** 2015 - 2016
Central South University Changsha, China
School of Mathematics and Statistics Transfer to Upenn
Advisor: Prof. Zhong Wan

B.S. in **Statistics** 2011 - 2015
Central South University Changsha, China
School of Mathematics and Statistics 90.41/100

Research Experience

The following projects are arranged in chronological order (by the project completion time).
The joint work not led by me: ♢

Exploration and Exploitation in Sequential Learning

University of Pennsylvania Philadelphia, PA, USA
Advisor: Prof. Shirin Saeedi Bidokhti, Prof. Saswati Sarkar Graduate Researcher

[**Description**]: Sequential learning and decision making in networked systems have attracted a lot of attention in the past few decades due to their increasing applications. One of the aspects that has barely been considered is the temporal and spatial evolution of processes in networks. For example, consider the spread of an infectious disease in a network of people, or the spread of misinformation in social networks. It is the design of "testing" strategies on networks in order to estimate and/or control the process of interest.

[**Achievements**]:

- Proposed a novel efficient backward-update algorithm that exploits the correlation among nodes'

states (imposed by the nature of the spread) to provide a better estimate of the infection probabilities.
- Proposed exploitation and exploration policies in which decision making is based on the infection probabilities that we sequentially estimate for the network nodes.
- Showed that the initial belief of infection probabilities, the global clustering coefficient and the time period when the disease spreading without intervention affect the performances of proposed policies. The worse initial belief, the larger clustering coefficient or the longer time period (when the disease spreading without intervention), the better performances of exploration policies.
- One journal paper is submitted to *Transactions on Machine Learning Research*.

Tradeoffs between Information Freshness and Channel Rate

University of Pennsylvania Philadelphia, PA, USA
Advisor: Prof. Shirin Saeedi Bidokhti Graduate Researcher

[**Description**]: Information timeliness is key for the technology of Internet of Things applications and it has therefore emerged as a communication design criteria. However, tradeoffs between timeliness and rate in broadcast networks are still not clear. The inherent tradeoff can be explained as follows. On the one hand, a higher rate can correspond to a smaller delay/age of information (AoI) (both in the sense that queues get emptied faster and that fewer uses of the network are needed in total to transmit a fixed number of information bits). On the other hand, to achieve high rates, we need to wait for the arrival of other packets and change transmission priorities to facilitate coding, and this can lead to a larger AoI.

[**Achievements**]:
- Proposed a novel framework of network AoI on the broadcast channels under transmission mechanism with coding. Based on the framework, policies were proposed in which coding actions, as opposed to users, are scheduled to attain desired tradeoffs between rate and age of information. (Near-)optimal coding policies with uncoded and coded caching are obtained.
- Two general lower bounds and an upper bound are derived on EAoI for any transmission policy. The bounds are functions of generation rates, erasure probabilities and target rate constraints.
- Simulation results reveal that (i) coding is beneficial, and the benefits increase with the number of users; (ii) a good approximation of proposed policies is obtained based on maximum clique size of information graph; (iii) the tradeoff between rate and AoI exists, which implies that the system has to sacrifice AoI to achieve a higher rate.
- Two conference papers have been published in *2019 IEEE ITW* and *2021 IEEE ISIT*, respectively, one journal paper has been submitted to *IEEE Transactions on Wireless Communications* (*TWC*).

Real-time Sampling and Estimation on Random Access Channels

University of Pennsylvania Philadelphia, PA, USA
Advisor: Prof. Shirin Saeedi Bidokhti Graduate Researcher

[**Description**]: In traditional communication designs, it is ofter assumed that information bits (or packets) are processed and stored at the sources, waiting to be reliably transmitted and replicated at the receiver node(s) with high rate and low latency. In the Internet-of-Things systems, however, we ofter have to deal with *real-time sampling and timely estimation* of underlying physical processes. In this work, we consider the problem of real-time sampling and timely estimation over a random access channel with M Markov (autoregressive) physical processes (sources). These processes are to be observed, sampled, and communicated wirelessly with a fusion center for timely esitmation. This is a common setting for example in enviromental monitoring. Intuitively, it is desired to have "timely" communication because each Markov process is best estimated by its most recent sample; Otherwise, rate, reliability and latency are not directly relevant.

[**Achievements**]:
- Two general classses of policies were investigated, i.e., oblivious and non-oblivious policies. In the

former class, decision making is independent of the processes. In the later class, decision making depends on the processes.
- Proved that minimizing the expected time-average estimation error, in the class of oblivious policies, is equivalent to minimizing the age of information. The lower and upper bounds on the minimum achievable estimation error were obtained.
- Proposed an optimal non-oblivious threshold policy based on the collision feedback and the local information of each node. The corresponding closed-form expression for the average estimation error was obtained.
- One conference paper has been published on *2021 IEEE International Conference on Computer Communications* (*INFOCOM*), one journal paper has been submitted to *IEEE Transactions on Wireless Communications* (*TWC*).

Information Freshness in Decentralized Random Access Channels

University of Pennsylvania Philadelphia, PA, USA
Advisor: Prof. Shirin Saeedi Bidokhti, Prof. Hamed Hassani Graduate Researcher

[**Description**]: Communication networks have witnessed a rapid growth in the past few decades and they have laid a path to the integration of intelligence into cyber-physical systems, the Internet of Things, smart cities, as well as healthcare systems. Today, stateof-the-art network communication strategies are considered reliable and high speed; nevertheless, they often do not perform satisfactorily for time-sensitive applications. As a matter of fact, it is often observed that as the capacity of a system is approached, the delay increases significantly and hence so does the age of information (AoI). This paper considers the problem of minimizing AoI over a *decentralized* random access channel. This setup is particularly relevant in remote estimation and control of processes that are observed from decentralized sensors in wireless networks.

[**Achievements**]:
- Designed decentralized age-based transmission policies and provided upper and lower bounds on the achievable AoI in interesting regimes of operation.
- Proved that the normalized age performance of a (stabilized) slotted ALOHA algorithm is approximately optimal in large number of sources when the sum arrival rate is below the infamous critical point $\frac{1}{e}$.
- Proposed two age-based thinning methods (adaptive and stationary thinning) in which transmitters selectively discard packets in order to mimic an effective (sum) arrival rate equal to $\frac{1}{e}$.
- Extended the proposed thinning mechanism is useful for other random access technologies. Proved that our age-based thinning methods attain the normalized age of $1/2C$ for any random access technologies which can achieve the throughput C.
- One conference paper has been published in *2020 IEEE International Symposium on Information Theory* (*ISIT*). One journal paper has been accepted by *IEEE Transactions on Information Theory* (*TIT*).

Resource Allocation in Wireless Networks

University of Pennsylvania Philadelphia, PA, USA
Advisor: Prof. Saswati Sarkar Graduate Researcher

[**Description**]: Wireless service providers are divided into (i) mobile network operators (MNOs) that lease spectrum from a regulator, and (ii) mobile virtual network operators (MVNOs) that obtain spectrum from one or more MNOs. In this work, we consider the economics of the interaction among MNOs and MVNOs. We seek to understand why and under what conditions the MNOs cooperate with the MVNOs by offering some of their spectrum to the MVNOs, and thereby inviting competition for a common pool of end users (EUs).

[**Achievements**]:
- Considered a sequential framework and a hybrid of a sequential and a bargaining frameworks in a

base case (one MNO and one MVNO) and two generalizations ((i) one MNO, one MVNO and an outside option, (ii) two MNOs and one MVNO).
- The optimal strategies were characterized analytically and numerically: (i) cooperation between MNO and MVNO can enhance the payoffs of both, while increased competition due to the presence of additional MNOs is beneficial to EUs but reduces the payoffs of the service providers; (ii) whether and by how much the different entities benefit due to the cooperation in spectrum acquisition decision is evaluated.
- Two papers have been published in *IEEE Transactions on Network Science and Engineering* (*TNSE*).

Non-asymptotic Coded Slotted Aloha♢

University of Pennsylvania Philadelphia, PA, USA
Advisor: Prof. Hamed Hassani, Prof. Shirin Saeedi Bidokhti Graduate Researcher

[**Description**]: The technology of Internet of Things (IoT) has brought new challenges in the design of multi-access communication systems. The number of users is very large, orders of magnitude larger than the blocklength. Clearly, coordinating all the users is infeasible in such scenarios and hence communication should be assumed uncoordinated. This has motivated the key challenge of coding for massive random access communication, where senders communicate their packets in a bursty manner at random times.

[**Achievements**]:
- Connections between Coded Slotted Aloha (CSA) and LDPC ensembles were used to analyze the performance of regular CSA in the non-asymptotic regime.
- A density evolution framework was provided to describe the dynamics of decoding, and fundamentally limits were found on the maximum channel load (the number of active users per time slot) that allows reliable communication.
- Scaling laws were established, describing the non-asymptotic relation between the probability error, number of users, and the channel load.
- One paper has been published in *2019 IEEE International Symposium on Information Theory* (*ISIT*).

Online-Offline Supply Chain Management

Central South University Changsha, China
Advisor: Prof. Zhong Wan Undergraduate Researcher

[**Description**]: Online retailing has rapidly grown all over the world (from 2015), since it seems more efficient than that by brick-and-mortar retailers, which has set up more than one seeling channel in the competing market. The BOPS (buy-online and pick-up-in-store) mode is an emerging business form of online-offline integration, where consumers pay for goods online and pick them up in a physical store. In this work, we seek to find the optimal retail price, consignment quantity and the rate of revenue sharing in practice.

[**Achievements**]:
- Optimal strategies for Online-Offline retailing under BOPS mode were proposed by constructing a *Stochastic* Nash equilibrium model.
- One paper has been published in *ANZIAM Journal*.

Teaching Experience

- **Stochastic Systems Analysis and Simulation**, teaching assistant, undergraduate graduate course, University of Pennsylvania, Electrical and Systems Engineering Department, 2020 Fall.
- **Information Theory**, teaching assistant, graduate course, University of Pennsylvania, Electrical and Systems Engineering Department, 2020 Spring.

Publications

corresponding author: *
contributed equally: †

Preprints

[P4] **X. Chen***, H. Nikpey, J. Kim, S. Sarkar, and S. Saeedi-Bidokhti, " Containing a Spread through Sequential Learning: to Exploit or to Explore?", *Transactions on Machine Learning Research*, under review.

[P3] **X. Chen***, R. Liu, and S. Saeedi-Bidokhti, "Timely Broadcasting in Erasure Networks: Age-Rate Tradeoffs (Journal Version)," *IEEE Transactions on Wireless Communications*, under review. [arXiv: 2102.08926]

[P2] J. Kim*, **X. Chen**, S. Saeedi-Bidokhti and S. Sarkar, "Tracing and Testing Multiple Generations of Contacts to COVID-19 Cases: Cost-Benefit Tradeoffs," *Royal Society Open Science*, under revision. [medRxiv, doi: https://doi.org/10.1101/2021.06.29.21259723].

[P1] **X. Chen***, X. Liao and S. Saeedi-Bidokhti, "Real-time Sampling and Estimation on Random Access Channels: Age of Information and Beyond (Journal Version)," *IEEE Transactions on Wireless Communications*, under review. [arXiv: 2007.03652]

Journal Articles

[J4] **X. Chen***, K. Gatsis, H. Hassani, and S. Saeedi-Bidokhti. Age of Information in Random Access Channels. *IEEE Transactions on Information Theory*, In Press, 2022. [arXiv: 1912.01473]

[J3] **X. Chen***, S. Sarkar, M. H. Lotfi. The Interplay of Competition and Cooperation among Service Providers (Part II). *IEEE Transactions on Network Science and Engineering*, vol. 7, no. 4, pp. 2815 – 2829, 2020.

[J2] **X. Chen***, S. Sarkar, and M. H. Lotfi. The Interplay of Competition and Cooperation among Service Providers (Part I). *IEEE Transactions on Network Science and Engineering*, vol. 7, no. 4, pp. 2799 – 2814, 2020.

[J1] **X. Chen**, Y. Liu, and Z. Wan*. Optimal Decision Making for Online and Offline Retailers under BPOS Mode. *ANZIAM Journal*, 58:187-208, 2016.

Conference Papers

[C6] H. Nikpey, J. Kim, **X. Chen**, S. Sarkar, S. Saeedi Bidokhti, "Group Testing with Correlation under Edge-Faulty Graphs", *IEEE International Symposium on Information Theory*, June, 2022.

[C5] **X. Chen**, R. Liu†, S. Wang†, S. Saeedi-Bidokhti, "Timely Broadcasting in Erasure Networks: Age-Rate Tradeoffs," *IEEE International Symposium on Information Theory*, July, 2021.

[C4] **X. Chen**, X. Liao and S. Saeedi-Bidokhti, "Real-time Sampling and Estimation on Random Access Channels: Age of Information and Beyond," *IEEE International Conference on Computer Communications*, May, 2021. [Student Conference Award] [Acceptance rate 19.9%]

[C3] **X. Chen**, K. Gatsis, H. Hassani, and S. Saeedi-Bidokhti. Age of Information in Random Access Channels. *IEEE International Symposium on Information Theory*, June, 2020

[C2] **X. Chen** and S. Saeedi-Bidokhti. Benefits of Coding on Age of Information in Broadcast Networks. *IEEE Information Theory Workshop*, August, 2019

[C1] M. Fereydounian, **X. Chen**, H. Hassani, and S. Saeedi-Bidokhti. Non-asymptotic coded slotted ALOHA. *IEEE International Symposium on Information Theory*, July, 2019

Technical Report

[TR1] **X. Chen**, S. Sarkar, and M. H. Lotfi. Supplementary Material for the Paper "The Interplay of Competition and Cooperation among Service Providers (Part I)". *Technical Report*, [arXiv: 1905.13423]

Thesis

[Th1] **X. Chen**. Competition and Cooperation between Service Providers. *Master's Thesis*, University of Pennsylvania, 2018.

Talks & Posters

[07/2021] [**Talk**] "Timely Broadcasting in Erasure Networks: Age-Rate Tradeoffs",*IEEE International Symposium on Information Theory*, virtual conference (due to COVID-19).
[05/2021] [**Talk**] "Real-time Sampling and Estimation on Random Access Channels: Age of Information and Beyond", *IEEE International Conference on Computer Communications*, virtual conference (due to COVID-19).
[06/2020] [**Talk**] "Age of Information in Random Access Channels", *IEEE International Symposium on Information Theory*, virtual conference (due to COVID-19).
[08/2019] [**Talk**] "Benefits of coding on age of information in broadcast networks", Southwest University, Chongqing, China.
[08/2019] [**Poster**] "Benefits of coding on age of information in broadcast networks", *IEEE Information Theory Workshop*, Visby, Sweden.
[07/2019] [**Talk**] "Non-asymptotic coded slotted aloha", *IEEE International Symposium on Information Theory*, Paris, France.
[07/2019] [**Poster**] "Benefits of coding on age of information in broadcast networks", *North American School of Information Theory*, Boston, USA.
[12/2015] [**Talk**] "Optimal Decision Making for Online and Offline Retailers under BOPS Mode", *The 6th International Conference on Optimization and Control with Applications*, Changsha, China.

Awards and Achievements

- IEEE INFOCOM Student Conference Award 2021
- IEEE ISIT Student Travel Grant 2019
- The Dean's Fellowship (University of Pennsylvania) 2018 - present
- Ganster Engineering Fellowship (University of Pennsylvania) 2018
- National Scholarship of China (Graduate Student) 2016
- First Prize of the 12th Graduate Students' Mathematical Modeling Contest in China 2015
- Student Representative at the 2015 Graduation Ceremony of Central South University 2015
- Outstanding Graduates of Hu'nan Province (Top 1% in Hu'nan Province) 2015
- Meritorious Winner of Mathematical Contest In Modeling (MCM) 2015
- National Scholarship of China (Undergraduate Student) 2014

Paper Review

Reviewer for Journals

- IEEE/ACM Transactions on Networking (ToN)
- IEEE Transactions on Network Science and Engineering (TNSE)
- IEEE Journal on Selected Areas in Communications (JSAC)
- IEEE Transactions on Communications (TCOM)
- IEEE Transactions on Wireless Communications (TWC)
- IEEE Transactions on Mobile Computing (TMC)
- IEEE Internet of Things Journal (IoT-J)
- IEEE Open Journal of the Communications Society (OJCOMS)
- IEEE Wireless Communications Letters

- Journal of Cleaner Production (JCLP)
- ANZIAM Journal
- Journal of Industrial and Management Optimization (JIMO)
- Mathematical Population Studies – An International Journal of Mathematical Demography
- Social Science Quarterly

Reviewer for Conferences

- IEEE ISIT (2020, 2022)
- IEEE ICC (2021)
- IEEE GLOBECOM Workshop (2020)
- Age of Information Workshop (2020)
- The Joint Optimization Conferences (2017)