1 Vision and Research Summary

My research focuses **automated parameter configurations** for future **Networks and Stochastic Systems**, with focus on data driven optimization and risk mitigation, and is strongly grounded in **optimization, learning and non-parametric statistics**.
To accommodate the huge amount of data exchange in the emerging wide range of applications such as the virtual and augmented reality (VR/AR), a critical piece that is still missing semantic network configurations in beyond 5G (B5G)/6G communication systems. Handcrafting the data and network operating parameters for each application in each network condition is inefficient. An alternative solution is to develop a learning framework that can adapt to the personalized requirement of each application in various operating environment automatically.
My research aims at designing network parameter configuration algorithms, with focus on: *1. Data-driven automated network parameter configurations; 2. Risk Mitigation and Anomaly Detection* Fig. 1 presents an overview of my research map. Details of my research plan can be found in Section 2 and 3.

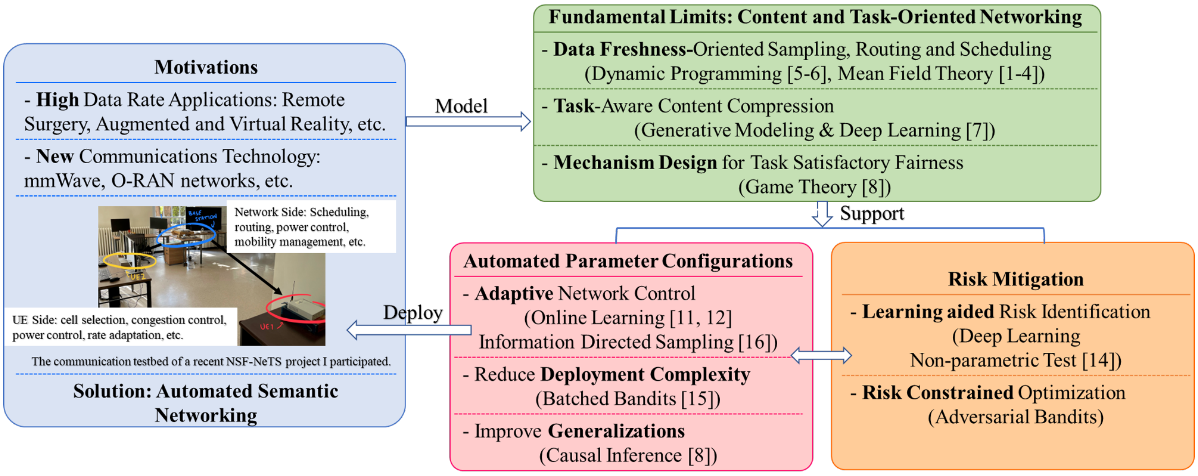

Figure 1: My research map on automated semantic networking: data-driven optimization and risk mitigation.

2 Data-Driven Semantic Networking

To date, I have proposed learning algorithms for data generation, scheduling and cross-layer scheduling in wireless network for optimizing the data freshness performance. Coupled with my prior work, I plan to improve the task completion and fairness performance in B5G/6G systems by understanding the resource requirements and finding the optimal operation point of cellular networks, developing advanced automated network configuration algorithms that dynamically coordinate data and network resource allocation.
Content and Task-Oriented Networking Framework The role of next generation networks is not just to carry bits between the transmitter and the receiver, but to support specific task completions at the receiver. I believe **content** and **task**-oriented network optimization is the key to improve task completion under communication resource constraints. To measure the freshness of the information (generated at the time-varying source) from the perspective of the information receiver, the metric–Age of Information has been proposed. My work [1, 2] propose the first low-complexity joint data sampling and cross-layer transmission algorithm that is **AoI optimum** in networks with massive number of access nodes. We show that to optimally manage the freshness of multiple sources through limited bandwidth, new samples of the sources should be taken when data stored at the user becomes stale, or the time-varying channel is under good conditions. By further taking the time-varying user and task requests into account, we develop in [3, 4] cache updating strategies so that users can fetch the freshest copies of time-varying files from the local cache. To catch the freshest sporadic updates (e.g., anomaly behaviors), by using the Age of Synchronization (AoS) as a freshness metric, we propose an AoS minimum uni-cast algorithm in multi-user networks and show that sources with smaller update frequency should be guaranteed transmission priority [5, 6]. Based on the initial success on data freshness performance through content and task oriented scheduling, I plan to extend the optimization framework to (1) **sensing and communication co-design** for B5G/6G systems[1] (2) **task-oriented content compression** with my expertise in high

[1] I recently applied for an NSF-NeTS Medium program on cooperative spectrum sharing as a senior personnel.

dimensional data modeling using conditional probability compatibility through deep neural networks [7]; (3) enhancing **task completion fairness** in network sharing through **mechanism design** [8].

Automated Network Parameter Configuration The standard practice in network resource management handcrafted parameter tuning using measurement analysis and performance feedback. I believe a more efficient way for operating wireless networks in B5G/6G new frequency bands is **data-driven parameter configuration** through **machine learning and non-parametric statistics**. To operate the aforementioned content and task oriented scheduling framework in an unknown environment, we propose an **online** sampling and flow control algorithm that can minimize the average AoI at the receiver [9, 10]. The original stochastic approximation algorithm developed by Robbins and Monro requires a coarse estimation of the approximated parameter and does not have a converse result. Our algorithm does not require such prior information and is proved to preserve the almost sure convergence properties. Using the Le Cam's two point method from non-parametric statistics, we then show our algorithm is **order optimal** under the worst case distribution. This algorithm can be generalized to the sampling and flow control problem in a wide range of time-varying process [11, 12]. To improve adaptivity, we improve the exploration strategies using the information directed sampling (IDS) [16]. The performance gain in network throughput and estimation error validate the effectiveness of data-driven solutions. In the long term, I will address the **deployment complexity** and **domain generalization** challenges in the current automated network parameter configuration algorithms: (1) lowering the deployment complexity with my expertise in batched bandits [15]; (2) improving the generalization performance to new carriers in B5G/6G systems by exploring the causal relationship between the network parameters and performance targets with my expertise in **causal inference** [17]; (3) efficient off-policy learning from historical data; (4) un-biased algorithm performance evaluation on testbeds.

3 Network Anomaly Detection and Risk Mitigation

Failures and inefficient performances can occur more frequently in B5G/6G systems due to higher operating frequencies, extreme mobility and massive number of accessing nodes. Leveraging my expertise in stochastic analysis and optimization, I plan to improve network robustness by designing risk-aware optimization algorithms.

Data driven risk identification To mitigate potential operating risks, it is important to identify anomaly behaviors and channel changes at an early stage, and resolve them quickly through interventions. I plan to develop **data-driven anomaly detection** algorithm using sensing data and features that are generated simultaneously with the communication process. Through non-parametric Kirmogorov-Smirnov test, we develop a channel change point detection algorithm [14, 13] and through joint change point detection and adaptive network parameter configuration, significant improvement on channel throughput and data freshness performance is obtained. In the future, I plan to improve anomaly detection accuracy by: (1) deriving the **fundamental trade-offs** between sensing accuracy and communication capacity and understanding system performance limits; (2). develop task specific collaborative sensing and fine grained risk identification algorithms by improving the **interpretability** of learning algorithms.

Provable Risk Constrained Multi-objective Optimization Besides optimizing the average network system performance over a long period, I believe it is crucial to develop algorithms whose risk (e.g., channel outage probability) will not exceed a certain threshold provably. To develop such risk constrained optimization algorithms, combined with the automated network parameter configuration framework, I intend to establish the lower bound on performance regret under the fact that a certain amount of risk events may happen, and develop risk aware adaptive learning algorithms for performance improvements.

4 Looking Ahead

The long-term goal of my research is to support diverse autonomous applications using B5G/6G networks systems. I will draw on various mathematical tools–from information theory, statistical inference, learning, and signal processing–in addressing important new problems that transcend traditional boundaries between disciplines.

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[2] * denotes undergraduates and junior graduate students working on projects with me.