Research Statement

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My research interests span the domains of **Networked Systems**, and I am particularly drawn to the challenges of constructing efficient, scalable, and secure network systems within diverse distributed applications, each presenting its unique set of constraints and tradeoffs. To this end, I also intend to rethink many already-existing abstractions that allow us to isolate these problems because, sometimes, the abstractions we synthesize can limit our perspective and discourage unconventional, innovative ways of thinking. My interests date back to when I enrolled in my first computer networks course during sophomore year, which showed me how to apply those theoretical algorithms and primitive data structures I had learned previously to erect beautifully practical systems. As I came to the realization that computer systems are where the many facets of Computer Science converge into tangible, real-world significance, an interest was sparked, which I pursued over the following semesters with my current advisor, Dr. Zafar Ayyub Qazi.

In the summer following my sophomore year, I interned at the Networks and Systems Group at LUMS where I learned about one of their critically acclaimed 5G research projects known as Neutrino, a fast and consistent Edge-based Cellular Control Plane. This understanding was gradually developed through self-studying the 4G LTE architecture and witnessing it in action through self-deployment of the OASIM-NEXTEPC profile on POWDER, all under the guidance of one of the MS students directly involved in Neutrino. Although limited, my exposure to **Cellular Networks** primed me for some degree of specialization as I joined in as a co-author on an extended submission for CellClone (under review at *IEEE/ACM Transactions on Networking*), a successor to Neutrino that addressed its shortcomings regarding fault tolerance. In short, CellClone took a more proactive, quorum-based approach, doing away with Neutrino's primary-based Cellular Core and instead opting for multiple control plane function (CPF) nodes to actively process user traffic. However, the original paper (published at *ACM CoNEXT'22*) assumed equidistant CPF nodes, contrary to real-life deployments, where they can be situated at different distances from a load balancer, leading to different completion times due to varying propagation delays. In my contribution, I introduced heterogeneity in the form of remote and local CPFs whilst adjusting the load balancer's forwarding mechanism to achieve distance-conscious quorums. Then, by tuning the configuration parameters and simulating different propagation delays, I measured PCT (Procedure Completion Times) over attach, handover, and service message traces to demonstrate the tradeoff between latency and fault tolerance that network operators can optimize for their constraints. The experience taught me how to structure large codebases, write Shell scripts, refactor code in both Python and C, and, most importantly, how to exercise patience when dissecting the inner workings of a large, complex, distributed system.

Then, towards the end of my Junior year, an acquaintance and I embarked on our own research-based senior-year project co-advised by Dr. Zafar Ayyub Qazi and Dr. Fawad Ahmed (RIT): MultiEdge-SLAM. The objective was to extend Edge-SLAM (built on ORB-SLAM2) for **Multi-Access Edge Computing**, empowering smartphones with limited computational capabilities to participate in **SLAM algorithms**, thereby enabling emerging AR/VR 5G applications. SLAM Algorithms are very complex algorithms that are not taught in typical Computer Science undergraduate programs, which is why I had to undergo a very extensive literature review period where I read and dissected the ORB-SLAM and Edge-SLAM papers before even beginning to address the problem. The problem was motivated by the fact that simply forcing Edge-SLAM to run across multiple edges meant reinitialization of the global map on each edge, causing relocalization due to loss of tracking. Moreover, since relocalization is significantly more difficult to recover from in large linear motion, this necessitates state migration on top of Edge-SLAM. Before implementing our state migration schemes, I traced out the entire KeyFrame generation pipeline over an eight-page document, an exercise that proved to be pivotal in both coding and debugging our schemes. Out of our three state migration schemes, I implemented our KeyFrame migration scheme first, which also laid the groundwork for the remaining schemes through the setup of additional TCP connections, queues, and a tri-state variable for triggered migration and handover mechanisms. I also came up with a new metric, Pose Precision Quotient (PPQ), that accounts for both accuracy (Absolute Pose Error) and number of matched poses to reconcile variations within accuracy brought about by high variance in KeyFrame generation. Our evaluation is currently underway, in which we are utilizing long, linear segments of KITTI datasets as they are more relevant to our use case. So far, this project has been a difficult yet rewarding journey, instilling the perseverance to go deep into unfamiliar classes of algorithms, the ability to devise robust evaluation methodologies and the self-awareness to always reason about the next step to take.

Aside from doing research, I am also very passionate about teaching. So far, I have served as a Teaching Assistant for two core Computer Science courses (**Data Structures** and **Network-Centric Computing**) and as a head Teaching Assistant for a graduate-level Computer Science Elective (**Distributed Systems**). Collectively, these opportunities have allowed me to experience everything there is to managing a course: from designing assignments (e.g., on Stacks/Queues and B-Trees) and their test cases to developing autograders and running plagiarism checkers (e.g., MOSS and JPlag); from creating and reviewing quizzes to invigilating and grading them; from supporting students of varying aptitudes through office hours to carefully planning assignment tutorial; from being a conscientious TA to a proactive Head TA - I've done it all.

All in all, my aspiration to contribute and advance research in networked systems, whether it be in academia or industrial labs, as well as inspiring students like myself to do the same, is what necessitates a Ph.D. The formidable journey of a Ph.D. program is a deliberate choice, providing the rigorous platform necessary to instill advanced research techniques, foster critical thinking, cultivate perseverance, nurture a self-accountable mindset, and enhance communication skills - the building blocks for impactful contributions to academia and industry.

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