Research Statement

My research interest is in the area of wireless communication networks. This is an area with an abundance of challenging and exciting problems such as cross-layer optimization, scheduling, congestion control, and sensor network applications. I believe that solutions to such problems need to be grounded in solid theory as well as implementable in practice. Based on this research philosophy, I present below my research experience and future research plans.

Research Experience

In recent years, wireless communication technology has dramatically evolved and widely deployed. It has already made a huge impact on our lives and is responsible for speeding up globalization all across the globe. Today, people can communicate virtually at anytime and anywhere. However, as wireless communications get increasingly prevalent, due to limited resources, efficient usage becomes both of paramount importance and an enormous challenge. In order to serve more uses with higher communication quality, it is imperative that we understand the fundamental limits that the wireless network systems can support, and how to achieve these performance limits in practice.

Current networked systems are often designed using multiple layers. In wireless communication systems, such layering could lead to highly inefficient network design because of a variety of factors unique to the wireless environment such as: time-varying channels, and interference. Thus, cross-layer approaches have been advocated over many years but not implemented because of their complex inter-layer interactions, and potential loss of robustness. However, in recent developments, it has been demonstrated that cross-layer optimization can be achieved with minimal interaction between the layers, which preserves the robustness of the solution. Nonetheless, it turns out the scheduling component has the highest complexity. Most scheduling schemes in the literature suffer from enormous complexity, non-provable performance guarantee, low throughput performance, slow convergence, and/or requirement of centralized information. The main objective of my research has been to develop simple, distributed scheduling solutions with provable performance guarantees.

(A) ***Random Access scheduling***

First, I have focused on random access techniques since it is a scheduling strategy often used in wireless networks due to its simplicity. I have developed a distributed *constant-time* random access scheduling with O(1) complexity and provable performance guarantee (see [1] in my publication list). The proposed scheduling method incorporates a link's attempt probability with its queue length. It successfully approximates the well-known centralized greedy scheduling algorithm with a fixed contention period. It also achieves at least half of the maximal achievable capacity under the primary interference model. In fact, simulations indicate that its performance approaches that of the optimal solution when the contention period is larger.

(B) ***Topological understanding of the greedy scheduling***

An interesting observation in my research on random access scheduling is that the greedy scheduling achieves optimal performance in most network scenarios, although it has been often referred to as a 2-approximate algorithm for the primary interference model. The greedy algorithm has been known for a long time as a simple sub-optimal alternative of the optimal solution. It has been utilized in many ways due to its low complexity and high performance. However, despite the enormous attention it has received, its precise performance limits have been unknown. I have characterized the performance of the greedy scheduling through a topological notion, called *local-pooling factor* [2]. Using flow-limits technique and a specific construction of traffic pattern, I have shown that the achievable performance fraction of the greedy algorithm is equivalent to the local-pooling factor. Based on this result, I have developed an iterative method for estimating the capacity region of greedy scheduling [3] (Its preliminary version won the INFOCOM 2008 Best Paper Award.) It shows how the performance of the greedy algorithm can improve under some topological restrictions. For example, under a general K-hop interference model, where two links within K-hop distance interfere with each other, the greedy scheduling algorithm is *an optimal solution in tree networks, and a 6-approximate algorithm in geometric network graphs*.

(C) ***Local greedy scheduling***

Although the greedy (maximal) scheduling has provably and empirically good performance, one of its main drawbacks is its requirement of centralized information. While recent studies have successfully implemented it in a distributed fashion, these have incurred extra complexity, which then becomes a major obstacle in implementing greedy scheduling in practice. The random access technique that I developed (and discussed earlier in (A)) could be used as an alternative because it approximates the greedy algorithm, but it requires a long contention period to achieve comparable performance. Due to this overhead, the increase in the contention period will effectively decrease the throughput, and possibly reduce the performance. To achieve both low complexity and high performance, I have developed local greedy algorithms, which schedule links in a contention-free fashion [4]. Under the new algorithms, only links with the largest queue length within their neighborhood are eligible for being scheduled at a time slot, and others remain unscheduled. Interestingly, I can show that these local and non-maximal scheduling schemes achieve the performance of centralized greedy maximal scheduling in most network settings. Empirical results also show that it has comparable average performance to the centralized greedy scheme and significantly outperforms state-of-the-art random access scheme.

(D) ***Performance of wireless sensor networks***

Recently, I have developed new scaling law for data aggregation accounting for retransmission delay and wireless interference in sensor networks. Unlike throughput performance studied in previous works, delay performance of wireless networks has remained as an open problem. As a first step, I have studied the asymptotic relationship between retransmission delays and reliability in lossy wireless sensor networks with data aggregation [5]. A new approach has been developed to improve the delay performance by exploiting diversity of wireless medium. It turns out that wireless broadcast is a useful tool that results in substantial performance gains with data aggregation, in particular when a high-level reliability is demanded.

Future Research Directions

I am interested in a variety of research topics including wireless network systems, cross-layer optimization, and sensor networks. The main focus of my research program will be in the development of practical algorithms based on strong theoretical foundation. Collaborations with researchers at other institutions in the areas of networks, communications, control, information theory, and computer engineering will not only widen our opportunity of opening new paradigm, but also enrich our problem set. Some of the research problems that I plan to work on are following.

(A) ***Wireless scheduling***

Although wireless scheduling has been extensively studied in the literature, there still remain many interesting, important, and challenging problems. I plan to focus on a few of important issues. First, we need to clarify the trade-off between achievable throughput, algorithmic complexity, and delay. Note that carrier-sensing multiple access (CSMA) algorithms and gossip-like algorithms, which may have low complexity, can achieve the optimal throughput at the cost of enormous queueing delay. Hence, it is clear that the delay is strongly connected to other performance metrics. I plan to develop wireless scheduling algorithms that are tunable between the different performance metrics. In my previous work, it has been observed that scheduling algorithms based on queue length such the greedy scheduling usually achieve excellent delay performance. Hence, it will be the first step to investigate them from the delay aspect.

Second, I plan to study wireless network systems with time-varying channels. In practice, the wireless channels are time-varying due to fading, user mobility, etc. Current wireless technology provides flexibility to change modulation and coding schemes according to the channel status, which brings time-varying properties to the network system. Although a centralized optimal solution has been known in these settings, the development of distributed algorithms amenable to implementation with a provable performance guarantee remains as an open problem. In this study, I will generalize practical wireless scheduling algorithms to the extent of the time-varying channels.

Note that wireless scheduling is a well studied subject, and there are many theoretical techniques and practical algorithms available in the literature. Hence, it is a good research area for students to initiate their own research.

(B) ***Cross-layer optimization***

Scheduling is one part of a set of problems that need to be studied together for optimizing user performance. As mentioned earlier, new intelligently designed cross-layer approaches have emerged as alternatives to the layered approach. Their goal has been to improve *efficiency* while keeping the advantage of layered structure, i.e., *modularity*. In general, it is very challenging to figure out how layers interact with each other in a cross-layer architecture. To this end, I plan to study cross-layer interactions focusing on scheduling algorithm, and figure out how scheduler should interact with congestion controller to improve the overall performance including delay, which has not been studied earlier. In particular, it would be very interesting to develop techniques to demonstrate how the improvements recently achieved in scheduling can be delivered to end users.

(C) ***Data aggregation in wireless sensor networks***

Data aggregation is an enormously important area in the emerging technology area of sensor networks. In-network data aggregation can play an important role in improving performance since it significantly reduces the amount of traffic while delivering right information. In this study, I plan to exploit wireless features with aggregation function and network topology. In this direction, I will investigate how techniques developed for non-sensor networks can be applied to sensor networks incorporating with data aggregation. My plan includes characterizing application-specific aggregation function, incorporating it with wireless network architecture, and developing implementable algorithms.

In summary, my prior and future research on wireless networking extensively utilizes theoretical tools and develops implementable solutions with provable performance. I believe that maintaining a good balance between theory and practice strongly motivates students and teaches them good research practices. Maintaining this balance is also important from the point of view of funding. Government agencies like NSF, DARPA, DoD, AFRL, DoE, and ONR often require interesting theoretical and practical research, while companies such as Qualcomm, AT&T, HP, and Samsung particularly emphasize results that are immediately applicable in the short term.

References

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