Optimizing power networks for tomorrow's smart cities

May 19 2017

Lehigh industrial engineering Ph.D. candidate Jie Liu won an IBM Ph.D. Fellowship Award to study power systems and data analytics at IBM Research-Ireland, one of 12 IBM research laboratories in the world. Credit: Christa Neu / Lehigh University

The modern city, says Jie Liu, can be considered a web of networks that should run like a healthy, well-tuned circulatory system.

Automobile traffic in this "smart city" should move almost constantly, stopping or slowing as little as possible at traffic lights, on freeway ramps and in traffic circles, says Liu, a Ph.D. candidate in industrial engineering.

Likewise, electricity should flow through power lines at an optimal rate, high enough to achieve maximum efficiency but not so high that wires overheat.

These streamlined flows of people and power, says Liu, are made possible by machines that process large quantities of data in real time and learn to make intelligent decisions.

Liu develops large-scale optimization algorithms, or mathematical models, and applies them to machine learning. His goal is to design a power-transmission system that meets the energy demands of a city with maximum efficiency and minimal cost.

Liu recently received the IBM Ph.D. Fellowship Award to study power systems and data analytics at IBM Research-Ireland, one of 12 IBM research laboratories in the world. The fellowship is given each year to 50 outstanding students worldwide.

IBM Research-Ireland conducts research into the Cognitive Internet of Things, cognitive integrated healthcare, interactive reasoning, data centric computing and the cloud and privacy.

As part of the fellowship program, Liu has been assigned a mentor from

IBM Research-Ireland. He will continue his research into power systems and data analytics and will likely spend part of the fall semester in Ireland or at the company's New York site.

Machine learning

As an example of machine learning or signal processing, Liu points to E-ZPass, the electronic toll-collection system that serves motorists in the eastern half of the United States and in Ontario, Canada. E-ZPass photographs the license plates of passing cars and employs optimization techniques to read the letters and numbers of license plates, even in blurry photos.

Machine learning is also used by online shopping sites such as Amazon to analyze a consumer's purchasing history and recommend similar products that the consumer might be interested in buying.

Liu's research focuses on the buses, or intermediate power stations, which take electricity from a power plant and distribute it to homes and businesses in a utility company's service area. He develops models that seek to determine the optimal number, and optimal location, of intermediate stations. He is also working on the development of fast solvers for the popular deep neural networks and other graphical models.

A utility company's goal, says Liu, is to transmit electricity from its intermediate stations with maximum efficiency. If a station's wires carry too much electricity, he says, they will exceed the station's voltage limits and overheat, with undesired consequences, shutting down or even igniting. If the wires carry too little electricity, the system loses efficiency.

"We want to find a middle point," says Liu. "We can never reach the voltage limit. On the other hand, if the amount of electricity being

transmitted is too low, efficiency is reduced. We want to be efficient but not get too close to the limit."

A second goal, says Liu, is to solve problems that arise as quickly as possible. "We want to speed up optimization for power networks," he says. "Our goal is to transmit power efficiently while solving problems as quickly as possible."

Power grids and other networks generate massive streams of data that must be processed and analyzed in real time. Liu and his group set up polynomial optimization problems (POPs) and solve them by randomly choosing coordinates of data, which can be solved in parallel by multiple machines at the same time to improve efficiency. This contrasts, he says, with the conventional technique, which is called the Newton method and is difficult to parallelize.

"The Newton method processes all the data," says Liu, "but it is not possible to do this with a power system because it generates so much data. Our method doesn't process all the data; instead, we pick coordinates, or bits of data, randomly. This greatly reduces the total amount of time needed to solve a problem.

"To solve a multidimensional problem using the traditional method took days and did not always yield a feasible solution. With our method, we can arrive at a feasible solution in several minutes to half an hour."

Liu and his group reported their results recently in an article titled "Hybrid Methods in Solving Alternating-Current Optimal Power Flows." The article was coauthored with Alan C. Liddell, Jakub Mareček and Martin Takáč. Takáč, an assistant professor of industrial and systems engineering, is Liu's Lehigh Ph.D. adviser. Mareček is with IBM-Ireland, and Liddell is with Notre Dame University.

Liu enrolled at Lehigh in 2013 after completing his M.S. in mathematics from the State University of New York at Buffalo. He holds a B.S. in mathematics from Nankai University in Tianjin, China. His other honors include the Dean's Doctoral Assistantship and Dean's Fellowship from Lehigh's P.C. Rossin College of Engineering and Applied Science, the Gotshall Fellowship from Lehigh, and the American Express Machine Learning Contest Award.

At Lehigh, Liu is part of a research group called Optimization and Machine Learning (OptML), which includes Takáč; Katya Scheinberg, the Harvey E. Wagner Endowed Chair Professor of Industrial and Systems Engineering; and Frank Curtis, associate professor of industrial and systems engineering.

Students in the OptML group receive support to present their work at international conferences. Liu's papers and posters have been accepted at conferences of Neural Information Processing Systems (NIPS), the Institute for Operations Research and the Management Sciences (INFORMS), the International Conference on Machine Learning (ICML); and the Machine Learning Symposium in New York City.

Liu and his fellow students are also encouraged to do industrial internships. Liu has completed internships with Siemens Corporate Research and IBM. This summer he will work in Boston with Mitsubishi's Electricity Research Laboratories (MERL) in data analytics. In 2012, he worked with Argonnes National Laboratory near Chicago.

"These are amazing opportunities," Liu says. "These are different companies, totally different. These internships connect us to industry. They give us the chance to do something we're interested in and to learn new knowledge at the same time.

"The professors in our group are very supportive. They really help us

learn how we can contribute and make an impact."

Provided by Lehigh University