

Energy-Efficient and Reconfigurable Network-on-Chips for IP Integration in Complex SoC Systems – IREE Program

Mei Yang¹, Hungshing Lau¹, and Cristina Alveraz²

¹Department of Electrical and Computer Engineering

²Department of Mathematics

University of Nevada, Las Vegas

E-mail: ¹meiyang@egr.unlv.edu, lau_shing@yahoo.com.hk,

¹cristina.1.61803398@gmail.com

ABSTRACT: The supplement IREE award to our NSF project award entitled “Energy-Efficient and Reconfigurable Network-on-Chips for IP Integration in Complex SoC Systems” provides the fund to support the training and research plan of the participating researchers at UNLV and Nankai University. With the support of IREE, we pre-trained three undergraduates in research at UNLV during Fall 2007 and Spring 2008 and sent two undergraduates to the Laboratory of Parallel and Distributed Processing directed by Prof. Yulu Yang at Nankai University to work on the related research for three months in Summer 2008. In the pre-training session, the students conducted literature study, research projects, and attended research seminars. In the summer session, the two students were involved in the research of developing virtual channel model for multi-path routing schemes and the interconnection network simulation software. Both students interacted with Prof. Yang and the students working in LPDP extensively. They obtained reasonable results during their stay in Nankai University. They had made good friends with the Chinese students and had valuable experience of Chinese culture through their visits to Beijing and Tianjin.

INTRODUCTION

In Apr. 2007, we received the NSF award entitled “Energy-Efficient and Reconfigurable Network-on-Chips for IP Integration in Complex SoC Systems”. This project focuses on investigating energy-efficient and reconfigurable Network-on-Chips (NoCs) to address the major challenges faced by Intellectual Property (IP) integration in complex System-on-Chip (SoC) systems, including energy efficiency, reconfigurability, scalability, and signal integrity. The objectives of the proposed work include:

- Task 1: Investigate reconfigurable Recursive Diagonal Torus (RDT)-based NoC architectures.
- Task 2: Investigate multi-path routing scheme.
- Task 3: Investigate the prioritized wormhole switching technique.
- Task 4: Develop prototype systems to test all the proposed solutions and tackle the system integration issues in building the prototypes.

The proposed research is partially based on our collaborated work with the Laboratory of Parallel and Distributed Processing (LPDP) directed by Prof. Yulu Yang at Nankai University, China. Motivated by the great prospect of our proposed work, we plan to build up a strong research team in NoCs. The supplement IREE award provides the fund to support the training and research plan of the participating researchers at UNLV and Nankai University. With the support of IREE, we pre-trained three undergraduates in research at UNLV during Fall 2007 and Spring 2008 and sent two undergraduates to the LPDP at Nankai University to work on the related research for three months in Summer 2008.

To recruit the participating undergraduate students, we have disseminated the IREE program flyers and emails throughout the university. We also requested the faculty in the Department of Electrical and Computer Engineering (ECE) to announce this opportunity in their classes. Three

undergraduate students were recruited to participate the pre-training session and two students were selected to participate the summer session at Nankai University. The two selected students are Hungshing Lau and Cristina Alveraz (a Hispanic female student). Hungshing is majoring in the ECE department and Cristina is majoring in Mathematics and minoring in Computer Science. Both of them have good GPAs. Especially, Hungshing has good background in digital and VLSI design, and Cristina has good programming skills. Their background and skills fit in our NSF project very well.

In the pre-training session, the students conducted literature study, research projects, and attended research seminars. Our research plan at Nankai University is focused on developing virtual channel model for multi-path routing schemes and efficient communication protocols and verifying them on the interconnection network simulation software developed in Prof. Yang's group.

The Laboratory of Parallel and Distributed Processing directed by Prof. Yulu Yang at Nankai University has extensive background and research experience in parallel architectures and interconnection networks. The LPDP was established in Sept. 1997. Currently, the LPDP has 3 faculty, 3 Ph. D. students, and 9 master students. Since 1997, the LPDP has graduated 4 Ph. Ds. and 18 masters. The director Prof. Yang received his Ph. D. from Keio University, Japan in 1996. His research areas include parallel and distributed systems, highperformance computing systems, networking, and grid computing. Prof. Yang has published over 20 international journals and conference papers in these areas. He proposed the RDT structure for interconnecting massive parallel computers while he was in Keio University. Due to its high performance, RDT is used as the interconnection network in the "Super Parallel Computing" project, which is one of the key national projects in Japan. Prof. Yang's research has been supported by National Science Foundation of China (NSFC), Ministry of Education, National Science Foundations of Tianjin, and Tianjin Municipality.

In summer 2008, three researchers traveled to China supported by the IREE award. The dates of their travel are listed below:

- Dr. Mei Yang (assistant professor), May 17 ~ Aug. 31
- Hungshing Lau (undergraduate student), May 18~Aug. 20
- Cristina Alveraz (undergraduate student), May 18~Aug. 17

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

Together with Dr. Yingtao Jiang, the Co-PI of this project, Dr. Mei Yang sent the two students to Nankai University on May 19. Drs. Yang and Jiang stayed in Nankai University for two days to coordinate with Prof. Yang in assigning the two student's research work and arranging their logistics. In the rest of the three months, Dr. Yang coordinated with Prof. Yang in supervising the two student's research work through phones and emails. She also collaborated with Prof. Yang in research related to multi-path routing scheme.

The major research work conducted by the two students is listed below:

- Hungshing Lau: During the pre-training session, Hungshing studied the layout problem of torus and PRDT-based NoCs on PCB board. He has designed several layout schemes and conducted the verification through experiments. During the summer, Hungshing participated the research project of developing deadlock-free virtual channel model [4] for multi-path routing scheme [2][3]. One important work in this study is implementing the virtual channel model in hardware and comparing the implementation cost with the best-known virtual channel model, named *Channel model proposed in [1]. At Nankai University, Hungshing implemented the *Channel model on torus-based routers in Verilog and synthesized the

design on QUARTUS II, the Altera's FPGA design tool. Hungshing's work is closely related to Tasks 2 and 4 in our NSF project.

- Cristina Alveraz: During the pre-training session, Cristina studied the layout problem of PRDT-based NoC from the theoretical aspect. She studied the program which implements the random layout and simulated annealing layout approaches for mesh and torus. She then modified the program to support RDT structure. During the summer, Cristina joined the programming work related to the interconnection network simulation software (SINOMP) developed in Prof. Yang's group. She first added a random number generator with Poisson distribution to SINOMP. She then studied various integer factorization algorithms and programmed the Multiple Polynomial Quadratic Sieve method. Cristina's work is related to the Task 1.

Prof. Yang closely supervised the two students during their stay in Nankai University. He first gave them an instructive orientation and two lectures in background knowledge in the first week. He met with the two students at least twice a week. Dr. Mei Yang also coordinated with Prof. Yang in supervising the students' research work by frequent emails and phone calls. She provided the software for Hungshing to use in his project. Each student has a team member in Prof. Yang's group. They worked closely with their team members (graduate students) on their assigned projects. Another two graduate students also worked in the lab most time. In each week, Prof. Yang's group held a seminar/discussion session as an open forum for all the students in the lab to discuss research problems and exchange ideas. Each of them was assigned a high-end desktop PC with Internet connection. The lab facility and people around provided them an open and friendly working environment. In this environment, both of them had reasonable accomplishments as described before.

The schedule of the summer session at Nankai University is listed below.

- Week 1-2: 1) attend the orientation on the first way which includes the introduction of the university environment, laboratory facility, and Chinese culture, tour of university, etc., 2) attend the lectures given by Prof. Yang on interconnection networks and packet switching, 3) choose research projects and make research plan.
- Week 3- 6: 1) join the research team, conduct preliminary study, and meet Prof. Yang at least twice a week, 2) attend the seminar held at Prof. Yang's group regularly, 3) trip to Beijing for culture exploration.
- Week 7-12: 1) conduct research and meet Prof. Yang at least twice a week, 2) adjust research plan after getting the feedback from Prof. Yang and Dr. Mei Yang, 3) attend the seminar held at Prof. Yang's group regularly, 4) trip to local attractions in Tianjin.
- Week 13: 1) wrap up the research work at Nankai University, 2) write the final report.

After the summer session, both students showed interest to continue working for the NSF project. Especially, Hungshing's work in summer provides the necessary results which can be put in a journal publication. He will continue to implement our virtual channel model and compare the results with the results of the *Channel model.

As we planned in the proposal, the IREE program provided the participating students the opportunity to gain useful research experience in the exciting field of NoCs. In this program, the students learned background knowledge in interconnection networks and NoCs, general research methodologies, programming skills in this field. They also exercised their written communication and oral presentation skills. Both students agreed that their study and living experience in China will benefit them in their future career and life. In addition, the proposed project and interaction activities benefited both the PIs' group at UNLV and Prof. Yang's group at Nankai University and strengthened the collaboration between the two groups. The research results generated from this project and the students trained in this project will leverage our NSF research project and provide useful resource for acquiring future fund in this field.

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

The IREE program helped fostering future collaboration between UNLV and Nankai University, which will promote the development of a diverse, interdisciplinary, internationally competitive, and globally-engaged Computer Engineering program at UNLV. Noticeably, the different backgrounds of the two participating students helped promoting the diversity of our NSF project. Hungshing is originally from HongKong. Crisitna is a Hispanic female student. Their experience in IREE program will help attract more students with diverse background to join our NSF project.

The IREE program opened the door to attract undergraduate students to participate in up-to-date research. The work conducted by the students demonstrated their creativity and research capability. Their contribution to our NSF project is recognizable. The students have gained useful knowledge and research experience in this program. One goal of our NSF project is to promote education in related fields, which has been achieved through the IREE program.

During the trip to Nankai University, both PIs met with Prof. Yang and discussed about future research collaboration plan. They will continue collaborating in Tasks 1 and 2 of our NSF project. Two journal papers are in preparation.

The two students experienced the rich culture of China and hospitality of Chinese people during their stay in Nankai University. Dr. Mei Yang took them to a culture exploration trip in Beijing, the capital of China. They visited Tiananmen Square, the Forbidden City, the Great Wall, and the Summer Palace. Both students were very impressed by the georgeous architectures and the historic values of these attractions. Together with their team members and other labmates, they also visited TianJin Ancient Cultural Street Tourist Area and TianJin Museum. The two students have made good friends with their team members and labmates.

They also explored the various Chinese food. They learned to speak Chinese. They were also impressed by the fast economic and technology development of China. Each of them got a cell phone, resident phone, and Internet connection at their dorm. They were quite satisfied with their living environment. The convenience of transportation in Tianjin and Beijing also impressed them a lot. They experienced subway and taxi in both cities.

DISCUSSION AND SUMMARY

All participants of the IREE program obtained valuable experience in their trip to China in both research and culture. We highly recommend the culture activities. We also recommend the pre-trip workshop to be held earlier in future IREE program.

ACKNOWLEDGEMENTS

This project is supported by the IREE supplement award to “Energy-Efficient and Reconfigurable Network-on-Chips for IP Integration in Complex SoC Systems”, NSF grant no. ECCS-0702168, supervised by NSF program officer Dr. Scott Midkiff.

REFERENCES

- [1] L. Gravano, G.D. PifarrC, P.E. Berman, and J.L.C. Sanz, “Adaptive deadlock- and livelock-free routing with all minimal paths in torus networks,” *IEEE Trans. Parallel and Distributed Systems*, vol. 5, no. 12, pp. 1233-1251, Dec. 1994.
- [2] Y. Jiao, Y. Yang, M. He, M. Yang, and Y. Jiang, “Multi-path routing for mesh/torus-based NoCs,” *Proc. Int’l Conf. Information Technologies: Next Generation (ITNG)*, 2007, pp. 734-739.

- [3] Y. Jiao, Y. Yang, M. Yang, and Y. Jiang, "A multi-path routing scheme for torus-based NoCs," to appear in *International Journal of Computers and Applications, Special Issue on High Performance Computing Architectures*, Jan. 2008.
- [4] Y. Jiao, M. Yang, Y. Yang, Y. Jiang, and X. Yun, "Deadlock-free multi-path routing for torus-based NoCs," *Proc. ITNG*, 2008, pp. 253-258.
- [5] G. Yang, M. Yang, Y. Yang, and Y. Jiang, "On the physical layout of PRDT-based NoCs," *Proc. ITNG*, 2007, pp. 729-733.

BRIEF BIOGRAPHIES OF RESEARCHERS

Mei Yang received her Ph. D. degree in Computer Science from the University of Texas at Dallas in Aug. 2003. She is currently an Assistant Professor in the Department of Electrical and Computer Engineering at University of Nevada, Las Vegas (UNLV). Before she joined UNLV, she was an Assistant Professor in the Department of Computer Science at Columbus State University from Aug. 2003 to Aug. 2004. Her current research interests include wireless sensor networks, mobile ad hoc networks, computer architectures, and embedded systems.

Hungshing Lau is currently a undergraduate in the Department of Electrical and Computer Engineering, University of Nevada, Las Vegas. He is expected to receive his bachelor degree in Fall 2008.

Cristina Huerta Alvarez received her B.S. degree in Mathematics & Minor in Computer Science in Aug. 2008. She plans on pursuing an applied computational mathematics master's degree & working for the federal government.