

Dr. Lingjie Duan

Associate Professor
Engineering Systems and Design Pillar
Singapore University of Technology and Design (SUTD)
8 Somapah Road, Singapore 487372

Tel: +65 6499 4508
Fax: +65 6779 5161
Email: lingjie_duan@sutd.edu.sg
<https://esd.sutd.edu.sg/people/faculty/lingjie-duan>

1. Brief Biography



Lingjie Duan is an Associate Professor in the Engineering Systems and Design Pillar at Singapore University of Technology and Design (SUTD). He received the B.Eng. degree from Harbin Institute of Technology in 2008, and Ph.D. degree in Information Engineering from The Chinese University of Hong Kong (CUHK) in 2012. He was a Visiting Scholar at University of California at Berkeley in the second half of 2011. Dr. Duan's research focuses on the optimization and economics of communication networks, especially in energy-harvesting communications, cognitive radio networking, and mobile crowdsourcing. He has been actively working and contributing to the inter-disciplinary research field combining communication engineering and economic theory. In this new field, he has many publications in top-tier engineering and business places, including 9 JSAC, 15 TMC, 13 TWC, 1 TON, 1 TSP, 1 TIFS, 2 TCOM, 2 TVT, 10 INFOCOM, 2 MobiHoc, 1 AAMAS, and 1 Production and Operations Management (POM). Among his recent publications, 5 journal papers were classified as ESI Highly Cited Papers by the ISI Essential Science Indicator on Web of Science. His publications have received 2700+ Google Scholar citations with an H-index of 28, and the citations are increasing rapidly with 600+ citations in 2018.

Dr. Duan's research work at SUTD has received high recognition from the research community. Particularly, he received the 2016 SUTD Excellence in Research Award, a prestigious award conferred annually to two SUTD tenure-track faculty members with significant impact and promise in research. He also received the 10th Asia-Pacific Outstanding Young Researcher Award conferred by the IEEE Communications Society in 2015, for contributions to "Economics and Optimization of Communication Networks." He was also a Finalist of the the Hong Kong Young Scientist Award in Engineering Science in 2014. Dr. Duan has served as an Editor of IEEE Transactions on Wireless Communications (2017/1-) and Editor of IEEE Communications Surveys and Tutorials (2016/1-). In 2016, he served as a Guest Editor of IEEE Journal on Selected Areas in Communications (JSAC) - special issue "Human-in-the-loop Mobile Networks," and he also served as a Guest Editor of IEEE Wireless Communications magazine - feature topic "Green networking and computing for 5G." In 2019, he also served as a Guest Editor of IEEE Transactions on Cognitive Communications and Networking. He is a regular technical program committee (TPC) member of leading conferences in communications and networking (e.g., IEEE INFOCOM, SECON, WiOPT, ICC, GLOBECOM, WCNC, and ACM MobiHoc). He is a Senior Member of IEEE and the IEEE Communications Society.

2. Education and Working Experience

- **Singapore University of Technology and Design (SUTD), Singapore** Aug. 2012 – Present
 - Associate Professor, Engineering Systems and Design (ESD) Pillar, Jun. 2019 – Present
 - Assistant Professor, Engineering Systems and Design (ESD) Pillar, Aug. 2012 – May 2019
- **University of California, Berkeley (UC Berkeley), USA** Jun. 2011 – Dec. 2011
 - Visiting Scholar, Department of Electrical Engineering and Computer Sciences
- **The Chinese University of Hong Kong, Hong Kong** Aug. 2008– Jul. 2012
 - PhD degree, Department of Information Engineering
- **Harbin Institute of Technology, China** Sept. 2004– Jul. 2008
 - Bachelor of Engineering, Department of Electrical Engineering

3. Individual Honors and Awards

- *The 2017 SUTD Long Service Award*, Singapore University of Technology and Design (SUTD), Jan. 2018.
- *The 2016 SUTD Excellence in Research Award*, Singapore University of Technology and Design (SUTD), Jan. 2017.
- *The 10th Asia-Pacific Outstanding Young Researcher Award*, IEEE Communications Society (ComSoc), 2015.
- *Finalist of Hong Kong Young Scientist Award (in Engineering Science)*, Hong Kong Institution of Science, 2014.
- *Award of Global Scholarship for Research Excellence*, The Chinese University of Hong Kong, 2011.

4. Professional Services

- Journal Editorships
 - 1) Editor, IEEE Transactions on Wireless Communications, 2017/1– Present
 - 2) Editor, IEEE Communications Surveys and Tutorials (with the highest SCI impact factor 17.2 among all Electrical Engineering and Telecommunications journals in 2016), 2016/1–Present
 - 3) Guest Editor, IEEE Transactions on Cognitive Communications and Networking - special issue for selected DySPAN papers, 2019.
 - 4) Guest Editor, IEEE Journal on Selected Areas in Communications - special issue “Human-in-the-loop Mobile Networks,” 2016.
 - 5) Guest Editor, IEEE Wireless Communications - feature topic “Green networking and computing for 5G,” 2016.
- Professional Memberships
 - 1) Senior Member of IEEE and the IEEE Communications Society (ComSoc)
 - 2) Member of IEEE Technical Committee on Cognitive Networks (TCCN)
 - 3) Member of IEEE Technical Committee on Green Communications and Computing (TCGCC)
 - 4) Vice-Chair, IEEE Special Interest Group (SIG) on Green and Sustainable Networking with Cognition and Cooperation
- Conference Service: Co-Chair
 - 1) Symposium Co-Chair, IEEE ICC 2019 Cognitive Radio and Networks Symposium.
 - 2) Workshop Co-Chair, IEEE WiOPT 2018 Conference.
 - 3) Track Co-Chair, 86th IEEE VTC 2017 Conference: Future Trends and Emerging Technologies track, Toronto, Canada.
 - 4) Publicity Co-Chair, IEEE WCNC 2017 Conference.
 - 5) Publication Co-Chair, 7th International EAI Conference on Game Theory for Networks (GameNets), 2017.
 - 6) Program Co-Chair, IEEE INFOCOM 2016 Workshop: Green and Sustainable Networking and Computing (GSNC), San Francisco, USA.
 - 7) Symposium Co-Chair, IEEE ICNC 2016 Conference: Green Computing, Networking, and Communications (GCNC) Symposium, Hawaii, USA.
 - 8) Symposium Co-Chair, IEEE ICC 2015 Conference: Wireless Communications Systems (WCS) Sympos-

sium, Shenzhen, China.

9) Program Co-Chair, IEEE INFOCOM 2014 Workshop: International Workshop on Green Cognitive Communications and Computing Networks (GCCCCN 2014), Toronto, Canada.

- Conference Service: Technical Program Committee (TPC) Member

- 1) IEEE International Conference on Computer Communications (INFOCOM), 2017 – 2018
- 2) ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc), 2016 – 2019
- 3) IEEE International Conference on Sensing, Communications, and Networking (SECON), 2016 – 2018
- 4) IEEE International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt), 2017-2018.
- 5) The 11th Workshop on the Economics of Networks, Systems and Computation (NetEcon), 2016
- 6) IEEE Wireless Communications and Networking Conference (WCNC), 2013–2017
- 7) IEEE International Conference on Communications (ICC), 2013–2017
- 8) IEEE Global Communication Conference (GLOBECOM), 2013 –2017
- 9) IEEE Vehicular Technology Conference (VTC), 2011, 2013 & 2017
- 10) IEEE International Conference on Smart Grid Communications (SmartGridComm), 2014 & 2015
- 11) International Conference on Computing, Networking, and Communications (ICNC), 2015–2016
- 12) International Conference on Design of Reliable Communication Networks (DRCN), 2015
- 13) International Conference on Game Theory for Networks (GAMENETS), 2016 & 2017
- 14) International Wireless Communications and Mobile Computing Conference (IWCMC), 2014
- 15) ACM Workshop on Mobility in the Evolving Internet Architecture (MobiArch), 2012–2013
- 16) The 22nd International Teletraffic Congress (ITC) Specialist Seminar on Energy Efficient and Green Networking (ITC SSENGN), 2013.
- 17) The 22nd IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2011), Toronto, Canada, Sept. 2011.

- Journal Technical Reviewer

- 1) IEEE Journal on Selected Areas in Communications (JSAC)
- 2) IEEE Transactions on Mobile Computing (TMC)
- 3) IEEE/ACM Transactions on Networking (TON)
- 4) IEEE Transactions on Wireless Communications (TWC)
- 5) IEEE Transactions on Signal Processing
- 6) IEEE Transactions on Communications (TCOM)
- 7) IEEE Transactions on Network Science and Engineering (TNSE)
- 8) IEEE Communications Surveys and Tutorials (COMST)
- 9) IEEE Transactions on Cognitive Communications and Networking (TCCN)
- 10) IEEE Communications Magazine
- 11) IEEE Wireless Communications Magazine
- 12) ACM Transactions on Internet Technology (TOIT)

- 13) IEEE Access
- 14) Communications of the ACM (CACM)
- 15) IEEE Transactions on Smart Grid (TSG)
- 16) IEEE Transactions on Vehicular Technology (TVT)
- 17) IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans
- 18) Wireless Communications and Mobile Computing
- 19) European Transactions on Telecommunications
- 20) Computer Networks, Elsevier
- 21) Tsinghua University PhD Thesis in the Discipline of Computer Science, 2018.
- 22) Proposals of the Singapore NRF Green Data Centre Programme, 2016.

5. Internal Service at SUTD

- Engineering Systems and Design (ESD) Pillar Services
 - 1) Member, ESD Graduate Committee, 2018 -
 - 2) Member, ESD Undergraduate Committee, 2016 - 2018.
 - 3) Member, ESD PhD Qualifying Exam Committee, 2016 -
 - 4) Co-lead, ESD 2D Project Showcase at SUTD Campus Centre, 2018 spring.
 - 5) Coordinator, ESD Teaching Assistant Allocation, 2016.
 - 6) Interviewer of applicants of ESD PhD program, 2015-
 - 7) Participant, ESD Seniors Reflection Session, 2016 & 2018.
 - 8) Presenter, Update of ESD Research Activities to Advisory Board, 2017.
 - 9) Participant, Admission & Career Talk Event, School of the Arts Gallery, 2017.
 - 10) Participant, Welcome Reception for New Batch of ESD Students, 2017.
 - 11) Participant, ESD Information Session, 2016-2017.
 - 12) Host, 8 ESD Distinguished Speaker Seminars, 2012 - 2017.
 - 13) Host, 3 ESD Research Seminars, 2012 - 2016.
 - 14) Faculty representative, 10 Overseas Recruitment Talks for the ESD PhD Program, 2012-2015.
 - 15) Faculty representative, Small Scale Discussion Sessions regarding Choice of Pillars, 2013.
 - 16) Interviewer, Faculty Search at INFORMS Annual Meeting in Phoenix, 2012.
- Other University Services
 - 1) Member, Institutional Review Board (IRB) Committee, 2018-
 - 2) Member, TAE Review Committee, 2017 -
 - 3) Member, Thesis Exam Committee for 6 PhD Students, ISTD & ESD, 2015-
 - 4) ESD Representative, Reflection with President and Associate Provost (Education), 2018/5.
 - 5) ESD Representative, University Research Board (URB) Meeting, 2018/5.
 - 6) Participant, Pillar CAP Meeting for Term 5/7, 2018.
 - 7) ESD Representative, UCC Meeting, 2017/11.

- 8) Participant, SUTD Offer Reception, 2018.
- 9) Member, MIT-SUTD Dual Masters' Programme, 2015-2016.
- 10) Interviewer, Global Exchange Selection Panel, 2016-2017.
- 11) ESD consultant, Service Design Module of Capstone, 2015.
- 12) Interviewer, SUTD Admission, 2013 - 2018.
- 13) Student Mentor, SUTD Mentorship Program, 2013 -
- 14) Participant, Reflection Meeting for Subjects, 2013 - 2017.
- 15) Participant, SUTD Open House, 2013-2018.

6. Research Publications

In total 2700+ citations in Google Scholar (with 600+ citations in 2018) with an H-index of 28

• Book Chapter and Monograph

- B1. J. Xu, **L. Duan**, and R. Zhang, "Cost-aware cellular networks powered by smart grid and energy harvesting," in the chapter of *Key Technologies for 5G Wireless Systems*, Cambridge University Press, 2017.
- B2. **L. Duan**, J. Huang, and B. Shou, *Cognitive Virtual Network Operator Games*, Springer Press, 2013.

• Journal Papers (including 9 JSAC, 15 TMC, 13 TWC, 1 TON, 1 TSP, 1 TIFS, 2 TCOM, 2 TVT, and 1 POM papers)

- 1) Y. Hsu, E. Modiano, **L. Duan** , "Scheduling Algorithms for Minimizing Age of Information in Wireless Broadcast Networks with Random Arrivals: The No-Buffer Case," *IEEE Transactions on Mobile Computing*, forthcoming. [Online]. Available: <https://arxiv.org/abs/1712.07419>
- 2) X. Wang and **L. Duan**, "Economic Analysis of Rollover and Shared Data Plans," *IEEE Transactions on Mobile Computing*, forthcoming. [Online]. Available: <https://arxiv.org/abs/1904.07970>
- 3) Z. Wang, **L. Duan**, and R. Zhang, "Adaptive Deployment for UAV-Aided Communication Networks," *IEEE Transactions on Wireless Communications*, forthcoming. [Online]. Available: <https://arxiv.org/pdf/1812.03267.pdf>
- 4) Y. Han, **L. Duan**, and R. Zhang , "Jamming-assisted eavesdropping over independent parallel fading channels," *IEEE Transactions on Information Forensics and Security (TIFS)*, forthcoming. [Online]. Available: <https://arxiv.org/pdf/1902.07420.pdf>
- 5) X. Zhang and **L. Duan** , "Fast deployment of UAV networks for optimal wireless coverage," *IEEE Transactions on Mobile Computing (TMC)*, forthcoming. [Online]. Available: <https://arxiv.org/abs/1710.05616>
- 6) X. Wang, **L. Duan**, and J. Zhang , "Mobile social services with network externality: from separate pricing to bundled pricing," *IEEE Transactions on Network Science and Engineering (TNSE)*, forthcoming. [Online]. Available: <https://arxiv.org/abs/1803.07496>
- 7) L. Wang, Y. L. Che, J. Long, **L. Duan**, and K. Wu, "Multiple Access mmWave Design for UAV-aided 5G Communications," *IEEE Wireless Communications*, forthcoming.
- 8) F. Wang, **L. Duan**, and J. Niu, , "Optimal Pricing of User-Initiated Data-Plan Sharing in A Roaming Market," *IEEE Transactions on Wireless Communications (TWC)*, vol. 17, no. 9, pp. 5929 - 5944, 2018.

[Online]. Available: <https://arxiv.org/pdf/1712.06236>

- 9) H. Kim, H. Lee, **L. Duan**, and I. Lee , “Sum-Rate Maximization Methods for Wirelessly Powered Communication Networks in Interference Channels,” *IEEE Transactions on Wireless Communications (TWC)*, vol. 17, no. 10, pp. 6464 - 6474, 2018.
- 10) Y. Chen, **L. Duan**, and Q. Zhang , “Financial Analysis of Network Upgrade,” *IEEE Transactions on Vehicular Technology (TVT)*, vol. 67, no. 6, pp. 5496 - 5499, 2018.
- 11) C. Jiang, L. Gao, **L. Duan**, and J. Huang , “Data-centric mobile crowdsensing,” *IEEE Transactions on Mobile Computing (TMC)*, vol. 17(6), pp. 1275–1288, 2018.
- 12) J. Xu, **L. Duan**, and R. Zhang, “Transmit optimisation for symbol-level spoofing,” *IEEE Transactions on Wireless Communications (TWC)*, vol. 17(1), pp. 41–55, 2018.
- 13) C. Jiang, L. Gao, **L. Duan**, and J. Huang , “Scalable mobile crowdsensing via peer-to-peer data sharing,” *IEEE Transactions on Mobile Computing (TMC)*, vol. 17(4), pp. 898–912, 2018.
- 14) K. Li, W. Ni, **L. Duan**, M. Abolhasan, and J. Niu , “Wireless power transfer and data collection in wireless sensor networks,” *IEEE Transactions on Vehicular Technology (TVT)*, vol. 67(3), pp. 2686–2697, 2018.
- 15) Y.P. Hsu and **L. Duan**, “To motivate social grouping in wireless networks,” *IEEE Transactions on Wireless Communications (TWC)*, vol. 16(8), pp. 4880–4893, 2017.
- 16) F. Gu, J. Niu, and **L. Duan**, “WAIPO: A fusion-based collaborative indoor localisation system on smartphones,” *IEEE/ACM Transactions on Networking (TON)*, vol. 25(4), pp. 2267–2280, 2017.
- 17) J. Xu, **L. Duan**, and R. Zhang, “Surveillance and intervention of infrastructure-free mobile communications: a new wireless security paradigm,” *IEEE Wireless Communications*, vol. 24(4), pp. 152–159, 2017.
- 18) Y. Li, C. Courcoubetis, and **L. Duan**, “Dynamic routing for social information sharing,” *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 35(3), pp. 571–585, 2017.
- 19) X. Gong, **L. Duan**, X. Chen, and J. Zhang, “When social network effect meets congestion effect in wireless networks: Data usage equilibrium and optimal pricing,” *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 35(2), pp. 449–462, 2017.
- 20) **L. Duan**, L. Huang, C. Langbort, A. Pozdnukhov, J. Walrand, and L. Zhang, “Human-in-the-loop mobile networks: A survey of recent advancements,” *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 35(4), pp. 813–831, 2017. (Tutorial+Editorial)
- 21) J. Xu, **L. Duan**, and R. Zhang, “Proactive eavesdropping via Cognitive Jamming in Fading Channels,” *IEEE Transactions on Wireless Communications (TWC)*, vol. 16(5), pp. 2790–2860, 2017.
- 22) J. Xu, **L. Duan**, and R. Zhang, “Fundamental rate limit of physical layer spoofing,” *IEEE Wireless Communications Letters (WCL)*, vol. 6(2), pp. 154–157, 2017.
- 23) **L. Duan**, B. Shou, and J. Huang, “Capacity allocation and pricing strategies for new wireless services,” *Production and Operations Management (POM)*, vol. 25(5), pp. 866–882, 2016.
- 24) Y. Che, **L. Duan**, and R. Zhang, “Dynamic Base Station Operation in Large-Scale Green Cellular Networks,” *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 34(12), pp. 3127–3141, 2016.
- 25) Z. Wang, **L. Duan**, and R. Zhang, “Adaptively directional wireless power transfer for large-scale sensor

- networks," *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 34, no. 5, pp. 1785-1800, 2016.
- 26) Y. Guo, L. Duan, and R. Zhang, "Cooperative local caching under heterogeneous file preferences," *IEEE Transactions on Communications (TCOM)*, vol. 65 (1), pp. 444-457, 2017.
 - 27) J. Xu, L. Duan, and R. Zhang, "Proactive eavesdropping via jamming for rate maximization over Rayleigh fading channels," *IEEE Wireless Communications Letters (WCL)*, vol. 5, no. 1, pp. 80-83, 2016.
 - 28) L. Gao, L. Duan, and J. Huang, "Two-sided matching based cooperative spectrum sharing," *IEEE Transactions on Mobile Computing (TMC)*, vol. 16(2), 538-551, 2017. **[This paper was an ESI Highly Cited Paper in 2017.]**
 - 29) S. Cai, Y. Che, L. Duan, J. Wang, S. Zhou, and R. Zhang, "Green heterogeneous networks through dynamic small-cell operation," *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 34, no. 5, pp. 1103-1115, 2016. **[An ESI Highly Cited Paper in 2018 (data from Web of Science).]**
 - 30) J. Xu, L. Duan, and R. Zhang, "Energy Group-Buying with Loading Sharing for Green Cellular Networks," *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 34, no. 4, pp. 786-799, 2016.
 - 31) C. Jiang, L. Duan, and J. Huang, "Optimal Pricing and Admission Control for Heterogeneous Secondary Users," *IEEE Transactions on Wireless Communications (TWC)*, vol. 15, no. 8, pp. 5218-5230, 2016.
 - 32) X. Wang, L. Duan, and R. Zhang, "User-initiated data plan trading via a personal hotspot market," *IEEE Transactions on Wireless Communications (TWC)*, vol. 15 (11), pp. 7885-7898, 2016.
 - 33) S. Gong, L. Duan, and N. Gautam, "Optimal scheduling and beamforming design in relay networks with energy harvesting constraints," *IEEE Transactions on Wireless Communications (TWC)*, vol. 15, no. 2, pp. 1226-1238, 2016.
 - 34) Y. Guo, L. Duan, and R. Zhang, "Optimal pricing and load sharing for energy saving with communications cooperation," *IEEE Transactions on Wireless Communications (TWC)*, vol. 15, no. 2, pp. 951-964, 2016.
 - 35) Y. L. Che, L. Duan, and R. Zhang, "Spatial throughput maximisation of wireless powered communication networks," *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 33, no. 8, pp. 1534-1548, 2015. **[An ESI Highly Cited Paper in 2018 (data from Web of Science).]**
 - 36) W. Wang, L. Chen, K. G. Shin, and L. Duan, "Thwarting intelligent malicious behaviors in cooperative sensing: A joint spectrum sensing and access framework," *IEEE Transactions on Mobile Computing (TMC)*, vol. 14, no. 11, pp. 2392 - 2405, 2015.
 - 37) J. Xu, L. Duan, and R. Zhang, "Cost-aware green cellular networks with energy and communication cooperation," *IEEE Communication Magazine*, vol. 53, no. 5, pp. 257-263, 2015. **[An ESI Highly Cited Paper in 2016 (data from Web of Science).]**
 - 38) Y. Chen, L. Duan, J. Huang, and Q. Zhang, "Balance of income and user utility in spectrum allocation," *IEEE Transactions on Mobile Computing (TMC)*, vol. 14(12), pp. 2460-2473, 2015.
 - 39) S. Gong, P. Wang, and L. Duan, "Distributed power control with robust protection for PUs in Cognitive Radio Networks," *IEEE Transactions on Wireless Communications (TWC)*, vol. 14, no. 6, pp. 3247-3258, 2015.
 - 40) Y. Che, J. Xu, L. Duan, and R. Zhang, "Multi-antenna wireless powered communication with co-channel

- energy and information transfer," *IEEE Communications Letters*, vol. 19 (12), pp. 2266–2269, 2015.
- 41) Y. Guo, J. Xu, **L. Duan**, R. Zhang, "Joint energy and spectrum cooperation for cellular communication systems," *IEEE Transactions on Communications (TCOM)*, vol. 62, no. 10, pp. 3678–3691, 2014.
 - 42) **L. Duan**, J. Huang, and B. Shou, "Pricing for local and global WiFi markets," *IEEE Transactions on Mobile Computing (TMC)*, vol. 14, no. 5, pp. 1056–1070, 2015.
 - 43) **L. Duan**, J. Huang, and J. Walrand, "Economic analysis of 4G upgrade timing," *IEEE Transactions on Mobile Computing (TMC)*, vol. 14, no. 5, pp. 975–989, 2015.
 - 44) J. He, **L. Duan**, F. Hou, P. Cheng, and J. Chen, "Multi-period scheduling for wireless sensor networks: A distributed consensus approach," *IEEE Transactions on Signal Processing (TSP)*, vol. 63, no. 7, pp. 1651–1663, 2015.
 - 45) **L. Duan**, L. Gao, and J. Huang, "Cooperative spectrum sharing: a contract-based approach," *IEEE Transactions on Mobile Computing (TMC)*, vol. 13, no. 1, pp. 174–187, 2014. **[An ESI Highly Cited Paper during 2014-2015.]**
 - 46) Y. L. Che, R. Zhang, Y. Gong, and **L. Duan**, "On spatial capacity of wireless ad hoc networks with threshold based scheduling," *IEEE Transactions on Wireless Communications (TWC)*, vol. 13, no. 12, pp. 6915–6927, 2014.
 - 47) **L. Duan**, T. Kubo, K. Sugiyama, J. Huang, T. Hasegawa, and J. Walrand, "Motivating smartphone collaboration in data acquisition and distributed computing," *IEEE Transactions on Mobile Computing (TMC)*, vol. 113, no. 10, pp. 2320–2333, 2014.
 - 48) Y. Yang, T. Quek, and **L. Duan**, "Backhaul-constrained small cell networks: Refunding and QoS provisioning," *IEEE Transactions on Wireless Communications (TWC)*, vol. 13, no. 9, pp. 5148–5161, 2014.
 - 49) **L. Duan**, J. Huang, and B. Shou, "Economics of femtocell service provision," *IEEE Transactions on Mobile Computing (TMC)*, vol. 12, no. 11, pp. 2261–2273, 2013.
 - 50) **L. Duan**, J. Huang, and B. Shou, "Duopoly competition in dynamic spectrum leasing and pricing," *IEEE Transactions on Mobile Computing (TMC)*, vol. 11, no. 11, pp. 1706–1719, 2012.
 - 51) **L. Duan**, A. W. Min, J. Huang, and K. G. Shin, "Attack prevention for collaborative spectrum sensing in cognitive radio networks," *IEEE Journal on Selected Areas in Communications (JSAC)*, vol. 30, no. 9, pp. 1658–1665, 2012.
 - 52) **L. Duan**, J. Huang, and B. Shou, "Investment and pricing with spectrum uncertainty: a cognitive operator's perspective," *IEEE Transactions on Mobile Computing (TMC)*, vol. 10, no. 11, pp. 1590–1604, Nov. 2011.

• **Conference Papers**

(including 10 INFOCOM, 2 MobiHoc, 1 AAMAS and 2 ISIT papers)

- 1) S. Hao and **L. Duan**, "Economics of age of information management under network externalities," to appear in the Twentieth International Symposium on Mobile Ad Hoc Networking and Computing (ACM MobiHoc 2019). (Acceptance Rate: 23.7%).
- 2) X. Wang and **L. Duan**, "Dynamic pricing and capacity allocation of UAV-provided mobile services," to appear in IEEE INFOCOM 2019 Conference. (Acceptance rate: 19.7%). [Online].

Available: <https://arxiv.org/pdf/1812.02910>

- 3) Y. Li, C. Courcoubetis, and **L. Duan**, "Recommending paths: Follow or not follow?" to appear in INFO-COM 2019 Conference. (Acceptance rate: 19.7%). [Online]. Available: <https://arxiv.org/pdf/1812.00574>
- 4) **L. Duan**, B. Li, M. Li, and X. Xu, "Heterogeneous two-facility location games with minimum distance requirement," to appear as a full paper in AAMAS 2019 Conference. (Acceptance rate: 24%).
- 5) Y. Li, C. Courcoubetis, **L. Duan**, and R. Weber, "Optimal pricing for a peer-to-peer sharing platform under network externalities," in Proc. of The 13th Workshop on the Economics of Networks, Systems and Computation (NetEcon), 2018. [Online]. Available: <https://arxiv.org/abs/1805.09616>
- 6) X. Wang and **L. Duan**, "Economics of UAV-provided mobile services," in Proc. of The 13th Workshop on the Economics of Networks, Systems and Computation (NetEcon), 2018.
- 7) X. Xu, **L. Duan**, and M. Li, "UAV placement games for optimal wireless service provision," in Proc. of IEEE WiOPT, 2018.
- 8) H. Zhang and **L. Duan**, "Going beyond Secrecy Rate via Information Jamming," in Proc. of IEEE GLOBECOM, 2018.
- 9) Z. Wang, **L. Duan**, and R. Zhang, "Traffic-aware Adaptive Deployment for UAV-Aided Communication Networks," in Proc. of IEEE GLOBECOM, 2018.
- 10) X. Zhang and **L. Duan**, "Optimization of emergency UAV deployment for providing wireless coverage," in Proc. of IEEE GLOBECOM, 2017.
- 11) J. Xu, K. Li, **L. Duan**, and R. Zhang, "Proactive eavesdropping via jamming over HARQ-based Communications," in Proc. of IEEE GLOBECOM, 2017.
- 12) F. Wang, **L. Duan**, and J. Niu, "Pricing for opportunistic data sharing via personal hotspot," in Proc. of IEEE GLOBECOM, 2017.
- 13) K. Li, W. Ni, **L. Duan**, M. Abolhasan, and J. Niu, "SWPT: a joint-scheduling model for wireless powered sensor networks," in Proc. of IEEE GLOBECOM, 2017.
- 14) Y.-P. Hsu, E. Modiano, and **L. Duan**, "Age of Information: Design and Analysis of Optimal Scheduling Algorithms," in Proc. of ISIT, 2017. [Online]. Technical Report: <https://arxiv.org/abs/1712.07419>
- 15) G. Ma, J. Xu, **L. Duan**, and R. Zhang, "Transmit Optimization for Symbol-Level Spoofing with BPSK Signaling," in Proc. of IEEE SPAWC 2017 as an invited paper.
- 16) H. Lee, **L. Duan**, and Y. Yi, "On the competition of CDN companies: Impact of new telco-CDNs federation," in *Proceedings of IEEE WiOpt Conference*, 2016.
- 17) J. Xu, **L. Duan**, and R. Zhang, "Proactive eavesdropping via cognitive jamming in fading channels," in *Proceedings of IEEE ICC Conference*, 2016.
- 18) Y. Guo, **L. Duan**, and R. Zhang, "Cooperative local caching and file sharing under heterogeneous file preferences," in *Proceedings of IEEE ICC Conference*, 2016.
- 19) J. Xu, **L. Duan**, and R. Zhang, "Transmit Optimization for Symbol-Level Spoofing with BPSK Signaling," in *Proceedings of GLOBECOM Workshop*, 2016.
- 20) J. Xu, **L. Duan**, and R. Zhang, "Harnessing Self-Interference in Full-Duplex Relaying: An Analog Filter-and-Forward Approach," in *Proceedings of GLOBECOM*, 2016.
- 21) C. Jiang, L. Gao, **L. Duan**, and J. Huang, "Exploiting data reuse in mobile crowdsensing," in *Proceedings*

of GLOBECOM, 2016.

- 22) X. Gong, L. Duan, and X. Chen, "When network effect meets congestion effect: Leveraging social services for wireless service," *ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc'15)*, 2015. [Acceptance rate: 14.8%]
- 23) Y. Chen, L. Duan, and Q. Zhang, "Financial analysis of 4G network deployment," in *Proc. of the 34th IEEE International Conference on Computer Communications (INFOCOM'15)*, 2015. [Acceptance Rate: 19%]
- 24) S. Gong, L. Duan, and P. Wang, "Robust optimization of cognitive radio networks powered by energy harvesting, in *Proc. of the 34th IEEE International Conference on Computer Communications (INFOCOM'15)*, 2015. [Acceptance Rate: 19%]
- 25) Z. Wang, L. Duan, and R. Zhang, "Adaptively directional wireless power transfer for large-scale sensor networks," in *Proc. of IEEE Global Communications Conference (GLOBECOM'15)*, 2015.
- 26) S. Cai, L. Duan, J. Wang, S. Zhou, and R. Zhang, "Incentive mechanism design for delayed WiFi offloading," in *Proc. of IEEE International Conference on Communications (ICC'15)*, 2015.
- 27) W. Wang, L. Chen, K. G. Shin, and L. Duan, "Secure cooperative spectrum sensing and access against intelligent malicious behaviors," in *Proceedings of the 33rd IEEE International Conference on Computer Communications (INFOCOM'14)*, Toronto, Canada, 2014. [Acceptance rate: 19%]
- 28) S. Cai, L. Duan, J. Wang, and R. Zhang, "Power-efficient heterogeneous networks through optimal small-cell scheduling," in *Proc. of IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, 2014.
- 29) C. Jiang, L. Duan, and J. Huang, "Joint dynamic pricing and spectrum allocation for heterogeneous secondary demands," in *Proceedings of the 13th International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt'14)*, Tunisia, 2014.
- 30) S. Gong, P. Wang, and L. Duan, "A game theoretic approach for robust power control in cognitive radio networks," in *Proceedings of IEEE Global Communications Conference (GLOBECOM'14)*, 2014.
- 31) Y. Guo, J. Xu, L. Duan, and R. Zhang, "Optimal energy and spectrum sharing for cooperative cellular systems," in *Proceedings of IEEE International Conference on Communications (ICC'14)*, Sydney, Australia, 2014.
- 32) Y. Chen, L. Duan, J. Huang, and Q. Zhang, "Balance of revenue and social welfare in FCC's spectrum allocation," in *Proceedings of the 32nd IEEE International Conference on Computer Communications (INFOCOM'13)*, Turin, Italy, Apr. 2013. [Acceptance rate: 17%]
- 33) L. Duan, J. Huang, and B. Shou, "Optimal pricing for local and global WiFi markets," in *Proceedings of the 32nd IEEE International Conference on Computer Communications (INFOCOM'13)*, Turin, Italy, Apr. 2013. [Acceptance rate: 17%]
- 34) L. Duan, J. Huang, and J. Walrand, "Economic analysis of 4G network upgrade," in *Proceedings of the 32nd IEEE International Conference on Computer Communications (INFOCOM'13)*, Turin, Italy, Apr. 2013. [Acceptance rate: 17%]
- 35) L. Duan and R. Zhang, "Dynamic contract to regulate energy management in microgrids," in *Proceedings of IEEE International Conference on Smart Grid Communications (SmartGridComm'13)*, Vancouver, Canada,

2013.

- 36) N. U. Hassan, S. Hussain, C. Yuen, and **L. Duan**, "Tradeoff between spectrum cost and quality of service in a cognitive radio network," in *Proceedings of IEEE Global Communications Conference (GLOBECOM'13)*, Atlanta, USA, 2013.
- 37) Y. Yang, T. Quek, **L. Duan**, "Backhaul-constrained optimization for hybrid access small cells," in *Proc. of IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP'13)*, Vancouver, Canada, 2013.
- 38) Y. Yang, T. Q.S. Quek, and **Lingjie Duan**, "Refunding for small cell networks with limited-capacity backhaul," *IEEE/CIC International Conference on Communications in China (ICCC'13)*, 2013.
- 39) **L. Duan**, J. Huang, and B. Shou, "Femtocell Service Provision with Dual Channel Competition," in *Proceedings of the Workshop on Telecom Economics, Engineering and Policy, The 24th International Teletraffic Congress (ITC 24)*, invited paper, Krakow, Poland, Sept. 2012.
- 40) K. Sugiyama, T. Kubo, **L. Duan**, A. Tagami, T. Hasegawa, and J. Huang, "Incentive mechanisms for secure smartphone collaboration," in *International Conference on Decision and Game Theory (GameSec)*, 2012.
- 41) **L. Duan**, T. Kubo, K. Sugiyama, J. Huang, T. Hasegawa, and J. Walrand, "Incentive mechanisms for smartphone collaboration in data acquisition and distributed computing," in *Proceedings of the 31st IEEE International Conference on Computer Communications (INFOCOM'12)*, Orlando, Florida, US, Mar. 2012. **[Acceptance rate: 17%.]**
- 42) **L. Duan**, L. Gao, and J. Huang, "Contract-based cooperative spectrum sharing," in *Proceedings of the 5th IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN'11)*, Aachen, Germany, May 2011.
- 43) **L. Duan**, J. Huang, and B. Shou, "Cognitive mobile virtual network operator: investment and pricing with supply uncertainty," in *Proceedings of the 29th IEEE International Conference on Computer Communications (INFOCOM'10)*, San Diego, CA, US, 2010. **[Acceptance rate: 17.5%.]**
- 44) **L. Duan**, J. Huang, and B. Shou, "Competition with dynamic spectrum leasing," in *Proceedings of the 4th IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN'10)*, Singapore, 2010.

7. Research Grants

- **External Research Funding (total individual funding under Lingjie's supervision: around SGD \$1.25 million)**

- 1) Principle Investigator, *Theory and Methods for User-provided Wireless Markets over Complex Networks*, MOE Academic Research Fund Tier 2, SGD \$0.44 million, 2017/2– 2020/2. (Lingjie Duan is the only PI.)
- 2) Co-Principle Investigator, *Advancing Security of Public Infrastructure using Resilience and Economics*, National Research Foundation (NRF), Singapore, SGD \$5.3 millions, 2015/1–2019/12.
(The PI is Aditya P. Mathur. Costas Courcoubetis and Lingjie co-lead the Economics Track with SGD \$0.4 million amount of funding. The individual amount supervised by Lingjie is around \$0.2 million.)
- 3) Co-Principle Investigator, *CISDeM: Cross-functional Information Systems for Decision Making*, Ministry of Defense, Singapore, SGD \$4.6 Millions, 2014/12 –2018/6. (The PI is David Yau, and Lingjie leads an IP

Geolocation Track with individual funding SGD \$0.61 million.)

- **Internal Research Funding (total individual funding under Lingjie's supervision: around SGD \$0.77 million)**

- 1) Principle Investigator, *Proactive information surveillance in wireless networks*, Seed Project under Temasek Laboratories, SGD \$50,000, 2016/6–2017/5. (Lingjie Duan is the only PI.)
- 2) Principle Investigator, *Green Wireless Networks with Energy and Communication Cooperation*, International SUTD-ZJU Collaboration Grant, SGD \$0.31 million, 2015/2 – 2018/2. (Lingjie Duan is the only SUTD PI.)
- 3) Co-Principle Investigator, *Cognitive Small Cells for Self-Organizing Networks*, SUTD-MIT International Design Center Grant, SGD \$0.61 million, 2013/1–2016/1. (The PI is Tony Quek, and Lingjie equally supervised around SGD \$0.30 million.)
- 4) Principle Investigator, *Incentive Mechanism Designs for Cognitive Radio Networks*, SUTD Start-up Research Grant, Singapore University of Technology and Design, SGD \$100,000, 2012/9–2015/9. (Lingjie is the only PI.)

8. Conference and Invited Presentations

- Conference Presentations

- 1) "Going beyond the secrecy rate via information jamming," in IEEE GLOBECOM Conference, Abu Dhabi, UAE, Dec. 2018.
- 2) "Traffic-aware adaptive deployment for UAV-aided communication networks," in IEEE GLOBECOM Conference, Abu Dhabi, UAE, Dec. 2018.
- 3) "A joint-scheduling model for wireless powered sensor networks," in IEEE GLOBECOM Conference, Singapore, Dec. 2017.
- 4) "When network effect meets congestion effect: Leveraging social services for wireless service," in ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc), Hangzhou, China, May 2015.
- 5) "Adaptively directional wireless power transfer for larger sensor networks," at IEEE GLOBECOM conference, San Diego, CA, USA, Dec. 2015.
- 6) "Economic analysis of 4G network upgrade," at the 32nd IEEE International Conference on Computer Communications (INFOCOM) conference, Turin, Italy, Apr. 2013.
- 7) "Optimal pricing for local and global WiFi markets," at the 32nd IEEE International Conference on Computer Communications (INFOCOM) conference, Turin, Italy, Apr. 2013.
- 8) "Incentive mechanisms for smartphone collaboration in data acquisition and distributed computing," at IEEE INFOCOM conference, Orlando, Florida, US, Mar. 2012.
- 9) "Contract-based cooperative spectrum sharing," at IEEE DySPAN conference, Aachen, Germany, May 2011.
- 10) "Economic viability of femtocell service provision," at GameNets conference, Shanghai, China, Apr.

2011.

- 11) "Competition with dynamic spectrum leasing," at IEEE DySPAN conference, Singapore, Apr. 2010.
- 12) "Cognitive mobile virtual network operator: Investment and pricing under supply uncertainty," at IEEE INFOCOM conference, San Diego, California, US, Mar. 2010.

- Invited Presentations

- 1) "Economic analysis of drone-provided mobile services," Invited talk at the 7th ACM MobiHoc Workshop on the Frontiers of Networks: Theory and Algorithms, July 2019.
- 2) "Incentive Design for Mobile Sensing and Computing," ESD Research Seminar, Singapore University of Technology and Design, Nov. 2015.
- 3) "Joint energy and communication cooperation for cost-aware communication networks," in Department of Information Engineering, Chinese University of Hong Kong, Hong Kong, Apr. 2015.
- 4) "Green and cooperative design for future wireless networks," College of Control Science and Engineering, Zhejiang University, Hangzhou, China, Dec. 2014.
- 5) "Economics of mobile cloud computing," *Panel Talk* in International Conference on Cloud Computing Research and Innovation (ICCCRI), Singapore, Oct. 2014.
- 6) "Economics of technology upgrade and smartphone collaborations in Cellular Networks," in School of Information Science and Technology, Tsinghua University, China, Jan. 2013.
- 7) "Economic analysis of cellular network upgrade," in Department of Electrical Engineering and Computer Sciences, University of California at Berkeley, Berkeley, CA, USA, Oct. 2011.
- 8) "Economics of cooperative spectrum sharing," in Department of Electrical Engineering and Computer Sciences, University of California at Berkeley, Berkeley, CA, USA, Jun. 2011.

9. Supervision of PhD Students and Postdocs

- Postdoctoral Research Fellows (5 in SUTD and 5 alumni)

- 1) Dr. Zhe Wang, (PhD from University of New South Wales, Australia), postdoc at SUTD, 2017-
- 2) Dr. Haiyang Zhang (PhD from Southeast University, China), postdoc at SUTD, 2017-
- 3) Dr. Xiao Zhang (PhD from City University of Hong Kong, Hong Kong), postdoc at SUTD, 2016-
- 4) Dr. Xuehe Wang (PhD from Nanyang Technological University, Singapore), postdoc at SUTD, 2015-
- 5) Dr. Pan Lai (PhD from Nanyang Technological University, Singapore), postdoc at SUTD, 2015-
- 6) Dr. Jie Xu (PhD from University of Science and Technology of China, China), postdoc at SUTD, 2015-2016. (Now in **China's Youth 1000-Talent Program** and a Full Professor at Guangdong University of Technology.)
- 7) Dr. Yu-Pin Hsu (PhD from Texas A&M University, USA), postdoc in the **SUTD-MIT Postdoctoral Programme** (jointly supervised with Prof. Eytan Modiano at MIT), 2014-2016. (Yu-Pin is now an Assistant Professor at National Taipei University.)
- 8) Dr. Yueling Che (PhD from Nanyang Technological University, Singapore), postdoc at SUTD, 2013-2016. (Now an Assistant Professor at Shenzhen University.)
- 9) Dr. Shimin Gong (PhD from Nanyang Technological University), postdoc at SUTD, 2014. (Now an Associate Professor in Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences.)

- 10) Dr. Shengming Cai (PhD from Nanyang Technological University), postdoc at SUTD, 2014. (Now a Research Engineer at Huawei Technologies.)
- PhD Students (6 in SUTD, 2 graduated from CUHK and NUS)
 - 1) Shu Hong: Bachelor from Southeast University (China), PhD student at SUTD, 2018-
 - 2) Shugang Hao: Bachelor from South China University of Technology (China), PhD student at SUTD, 2017-
 - 3) Shuqin Gao, Bachelor from Shanghai Jiao Tong University (China), PhD student at SUTD (co-supervised by Costas Courcoubetis), 2017-
 - 4) Yitao Han: Bachelor from Zhejiang University (China), SUTD-NUS Joint PhD student (co-supervised by Rui Zhang), 2016 -
 - 5) Xinping Xu: Bachelor from Nanjing University (China), PhD student at SUTD, 2015 -
 - 6) Yunpeng Li: Bachelor from Zhejiang University (China), PhD student at SUTD (co-supervised by Costas Courcoubetis), 2014 -
 - 7) Changkun Jiang: Master from Chinese Academy of Science, PhD student at CUHK (co-supervised with Jianwei Huang), 2012 - 2017. (Now an Assistant Professor at Shenzhen University.)
 - 8) Yinghao Guo: Bachelor from Dalian University of Technology, Co-supervised PhD student at National University of Singapore (co-supervised with Rui Zhang), 2012 - 2016. (Now a Research Engineer at Huawei Technologies.)

10. Recent Research Collaborators

- 1) Prof. Eytan Modiano, Laboratory for Information and Decision Systems, MIT, USA
- 2) Prof. Jean Walrand, Dept. of EECS, University of California at Berkeley (UC Berkeley), USA
- 3) Prof. Kang G. Shin, Dept. of EECS, University of Michigan (UMich), USA
- 4) Prof. Junshan Zhang, School of Electrical, Computer and Energy Engineering, Arizona State University, USA
- 5) Prof. Natarajan Gautam, Industrial & Systems Engineering, Texas A&M University (TAMU), USA
- 6) Prof. Richard Weber, Dept. of Pure Mathematics and Mathematical Statistics, University of Cambridge, UK.
- 7) Prof. Xiaojun Lin, School of Electrical and Computer Engineering, Purdue University, USA
- 8) Prof. Qian Zhang, Department of Computer Science and Engineering, Hong Kong University of Science and Technology (HKUST), Hong Kong
- 9) Prof. Jianwei Huang, Dept. of Information Engineering, The Chinese University of Hong Kong, Hong Kong
- 10) Prof. Biying Shou, Dept. of Management Sciences, City University of Hong Kong, Hong Kong
- 11) Prof. Rui Zhang, Dept. of Electrical and Computer Engineering, National University of Singapore (NUS)
- 12) Prof. Costas Courcoubetis, Singapore University of Technology and Design, Singapore
- 13) Prof. Tony Quek, Singapore University of Technology and Design (SUTD), Singapore
- 14) Prof. Yung Yi, Department of Electrical Engineering, KAIST, South Korea
- 15) Prof. Jiming Chen, Department of Control, Zhejiang University, China
- 16) Dr. Kenichi Maruhashi, Smart Energy Research Labs, NEC Corporation, Japan
- 17) Dr. Alex W. Min, Research Scientist, System Architecture Lab, Intel Labs, USA
- 18) Dr. Teruyuki Hasegawa, Senior Research Engineer, KDDI R&D Labs, Tokyo, Japan

11. Courses Taught at SUTD

- 1) Lecturer and Subject Co-Lead, 40.012 Manufacturing and Service Operations, Term 5, 2018.
- 2) Lecturer and Subject Lead, 40.316 Game Theory, Term 8, 2016 – 2018.
- 3) Lecturer and Subject Lead, 40.005 Introduction to Stochastic Modelling, Term 5, 2015–2017.
- 4) Cohort Instructor, 10.007 Modelling System World, 2013–2017.
- 5) Cohort Instructor, 01.400 Capstone, Term 7 & 8, 2015.
- 6) Lecturer, 01.001 Probability and Statistics, Term 4, 2014.
- 7) Lecturer and Subject Lead, 01.001 Probability and Statistics, Term 4, 2013.
- 8) Cohort Instructor, 10.004 Advanced Math II, Term 2, 2012.

12. Hosted Visitors or Research Seminars at SUTD

- 1) 12/2018: Prof. Xiangyun Zhou, Research School of Electrical, Energy and Materials Engineering, The Australian National University.
- 2) 12/2017: Prof. Thomas Hou, Dept of Electrical and Computer Engineering, Virginia Tech, USA.
- 3) 12/2017: Prof. Meixia Tao, Dept of Electronic Engineering, Shanghai Jiao Tong University, China.
- 4) 12/2017: Prof. Jianwei Huang, Department of Information Engineering, The Chinese University of Hong Kong
- 5) 11/2017: Prof. Nirwan Ansari, Dept of Electrical and Computer Engineering, New Jersey Institute of Technology, USA.
- 6) 7/2016: Prof. Kang G. Shin, Dept. of EECS, Michigan University, USA.
- 7) 3/2016: Prof. Chuan Wu, Dept. of Computer Science, The University of Hong Kong.
- 8) 10/2015: Prof. Yung Yi, Dept. of Electrical Engineering, KAIST, Korea.
- 9) 5/2015: Prof. Jun Luo, School of Computer Engineering, Nanyang Technological University, Singapore.
- 10) 3/2014: Prof. Michael Honig, Dept. of Electrical Engineering and Computer Science, Northwestern University, USA.
- 11) 1/2014: Prof. Eytan Modiano, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology (MIT), USA.
- 12) 3/2013: Prof. Jeonghoon Mo, Department of Information and Industrial Engineering, Yonsei University, Korea.