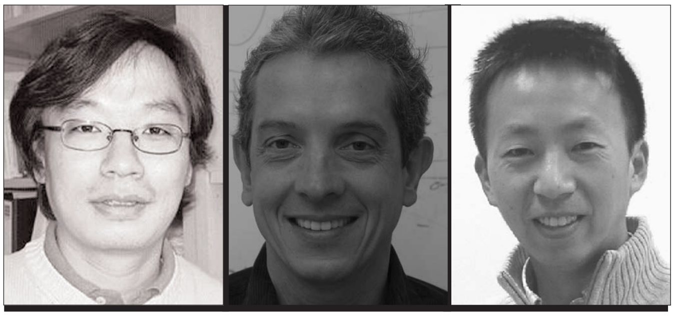
GUEST EDITORIAL

WIRELESS COMMUNICATIONS IN NETWORKED ROBOTICS



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Over the last two decades, the success of wireless communications has exceeded our expectations, from both the marketing and technological aspects. It is evolving toward next-generation systems that will support wireless services in the most spectral and energy- efficient ways. At the same time, we have observed rapid technical advances in radio access. Among other areas, we would like to draw attention to the following aspects.

Wireless multihop communications: Wireless multihop communications has been a key research issue in recent years in both academia and the wireless industry. It includes ad hoc radio networks, sensor networks, wireless mesh networks, and mobile multihop relay systems. With multihop capability, wireless communications can be combined with cooperative communications and network coding, which have attracted even more researchers. In many wireless multihop networks the merits of capacity enhancement and coverage extension go beyond the delay caused by multihop relay. However, there are unresolved issues that may not necessarily be technical; one question regards the motivation of a relay node to allow packet relay for others by consuming its own energy. There is also a security issue in multihop communications: one's own data transmission is received by someone else in close proximity. Multiple hops also increase latency and jitter, which is problematic if real-time communication is needed. In this regard there is still controversy over commercialization of wireless multihop communications.

Node mobility: In wireless communications node mobility is an important service to users. On the other hand, mobility does not come free, as one needs to deal with channel fading on both large and small scales. Handling node mobility has been a difficult task in all layers of communication protocols. Recently, there has been a group of researchers investigating exploitation of node mobility for enhancing network capacity. Nevertheless, node mobility is regarded as uncontrollable in wireless system design. However, if we could control node mobility (position, speed, etc.), we might then think of cross-layer optimization with node mobility (e.g., mobility and MAC, mobility and routing, mobility and transport control). Still, it is not clear in which applications we can control node mobility and take that into acount for cross-layer optimization.

Networked robots: Multiple robots with communication functions have been studied in the automatic control and robotics society. While it started with a client-server type communication prototype between robots and an access point, it has now evolved toward teams of robots supported by wireless ad hoc networks. The main motivation for connecting the robots is to achieve a common mission of the robots in a distributed and parallel manner. In many practical applications this approach is more efficient and economical than the approach with a single intelligent robot. Recently, many researchers note group behaviors found in small insects or animals such as ants, birds, and fish, trying to mimic such behaviors through the control and coordination of a team of robots with their local interactions. The classical robotic approaches need to model the environments based on sensors and actuators, and also to analyze behaviors of members in a group of robots. However, effective communication among robots is a difficult issue in the coordination of group behavior. Real-time wireless communication can help dynamic resource management and self-organization for a team of cooperative robots. The multiple robots communicate with each other, sharing the same mission. In this respect wireless communication is an excellent candidate for inter-robot information exchange.

Machine-to-machine communications: Machine-to-machine wireless communications will become more important than the current paradigm that focuses on machine-to-human or human-to-human information exchange. It will open new research challenges to wireless system designers. With this paradigm shift, the average distance between communication pairs will continuously decrease. This shortened distance will shape the radio network to be far more interference-limited. The randomness of the network will be expanded in terms of node mobility, interference, and energy consumption. It would be a difficult task to design effective communication protocols for handing such randomness.

This special issue is an attempt to bridge two areas, wireless communications and networked robotics, and also to provide a common ground for both fields. We have chosen five articles. First, Birk *et al.* introduce the issues of safety, security, and rescue robotics (SSRR), which constitutes one of the major applications in the networked robotics area; networked mobile robots can be applied to exploration of dangerous and inaccessible environments. In their article the authors introduce issues and problems of wireless communications for the ad hoc networking of multiple robots, and propose a communication framework for teleoperation in SSRR, together with field tests.

One such specific SSSR example can be found in the group of communicating robots where the mission is to move toward a position while keeping a predefined formation of the robots (like marching soldiers) . From the wireless communications perspective, such group behavior can be supported by efficient routing and media access control (under node mobility), which should then be cross-optimized and combined with control algorithms. The article by Pohjola *et al.*, investigates the issue in controlling multiple networked robots using efficient routing algorithms and a packet prioritization scheme. They report simulation results using a simulator developed at Helsinki University of Technology.

The article by Tekdas *et al.* investigates the problem of collecting data from the sensor nodes using traveling robots. The main motivation is to save energy in sensor nodes by providing "delivery service" for the sensed data to sink noded. At first glance, the issue is related to the traveling salesman problem (TSP). Unfortunately, the so-called data harvest problem is even more complicated due to the interdisciplinary issues of localization, robot path planning, and communication protocols.

The article by Lindhé and Johansson investigates communication-aware motion control issues. In the article the authors consider the idea of "surfing on fading channels" by mobile robots that communicate with a base station. The authors provide new insights into mobility control of multiple communicating nodes (robots). Robots can control their motion to communicate at better positions in radio channels. Two strategies, periodic stopping and controlled stopping, can improve average channel capacity of the robots. The article by Smith *et al.* is related to the Lindhé and Johansson article, where the authors report their measurement results on the gain of moving to a better position under fading channels. The gain, known as RF-Mobility Gain, is investigated empirically over a wide range of frequencies.

For this special issue, we received 36 papers, ranging from robot path planning to underwater wireless robots to the ad hoc network routing design for robot teams. The growing interest in this interdisciplinary subject is obvious from the large number of submissions. Due to space limitations, many high-quality papers could not be included. In particular, we regret those that were not included because the papers are more suitable to transactions rather than the more general readers of *IEEE Wireless Communications*.

The guest editors would like to thank the authors of all submissions. The experts are selected from both the robotics and communication fields to ensure a fair and rigorous review procedure. The guest editors would like to appreciate many experts who undertook the demanding review process. Finally, we would like to thank the Editor-in-Chief, Prof. Abbas Jamalipour, for giving us helpful guidelines.

BIOGRAPHIES

SEONG-LYUN KIM is a professor of wireless networks at the School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, heading the Radio Resource Management and Optimization Laboratory. Prior to joining Yonsei, he was an associate professor at the Information and Communications University, Taejon, Korea and an assistant professor at the Radio Communication Systems Group, Department of Signals, Sensors and Systems, Royal Institute of Technology, Stockholm, Sweden. His research interests include radio resource management and information theory in wireless networks, and networked robotics. He served as an Associate Editor for *IEEE Transactions on Vehicular Technology*, and is currently an Editor of the *Journal of Communications and Networks*. He received his B.S degree in economics from Seoul National University, Korea, in 1988, and M.S. and Ph.D. degrees from Korea Advanced Institute of Science and Technology in 1990 and 1994, respectively, in management science with applications to wireless networks.

WOLFRAM BURGARD is a professor of autonomous intelligent systems at the Department of Computer Science of the University of Freiburg. He studied computer science at the University of Dortmund and received his Ph.D. from the University of Bonn in 1991. He then became a post-doctoral researcher and head of the research group on autonomous mobile systems at the University of Bonn. In 1997 he and his group deployed the mobile robot Rhino as the first interactive mobile tour guide robot in the Deutsches Museum Bonn, Germany. The control system of this robot was substantially based on probabilistic algorithms and for the first time demonstrated that probabilistic techniques are a basis for reliable mobile robot navigation systems. He has published over 150 papers and articles in scientific conferences and journals. He received seven best paper awards from outstanding conferences in artificial intelligence and robotics. In 2008 he became a Fellow of the European Coordinating Committee for Artificial Intelligence.

DAEEUN KIM received his B.E. and M.Sc. in engineering from the Department of Computer Science and Engineering of Seoul National University and the University of Michigan at Ann Arbor, respectively. He was a lecturer in Korea Air Force Academy from 1994 to 1997 and then joined a research team involved with the bus-underground smartcard ticketing system in Seoul. He received a Ph.D. degree from the University of Edinburgh in 2002. From 2002 to 2006 he was a research scientist at the Max Planck Institute for Human Cognitive and Brain Sciences. From 2006 to 2007 he was a research associate at the Neurobiology Laboratory of the University of Leicester, United Kingdom. Currently he is an assistant professor at Yonsei University. His research interests are in the area of biorobotics, autonomous robots, artificial life, and neural networks.