THE FUTURE OF WI-FI


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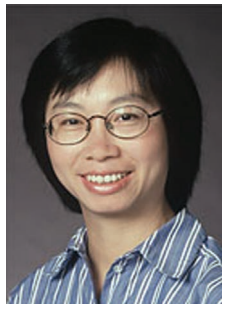
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Driven by the rapidly increasing demand for high data rate services and usage in a spectrum of application areas, wireless systems are compelled to evolve in order to meet the extraordinary performance requirements, especially in terms of spectral efficiency, coverage, latency, and energy efficiency. Regarding wireless local area networks, the first few widely accepted amendments to IEEE 802.11 wireless networking specifications, IEEE 802.11b/a/g, featured low spectral efficiencies, which are becoming insufficient to satisfy explosive traffic growth and the ever increasing consumer connectivity demand. With the soaring cost of the limited bandwidth at the 2.4 GHz frequency band, sustained improvement in spectral efficiency and quality of service has been achieved in IEEE 802.11n, which is mainly driven by advances in communication theory and the use of the 5 GHz frequency band. Specifically, the successive introduction of novel techniques such as multiple-input multiple-output (MIMO) antenna techniques and space-time coding, and the massive improvement in hardware and processing power, have enabled progressive system improvement. The introduction of advanced transmission techniques in recent years, notably multiuser MIMO and transmit beamforming, has provided additional powerful means for boosting the performance of Wi-Fi to gigabit per second speed and leading to the emerging IEEE 802.11ac. This is followed by the future introduction of IEEE 802.11ad products utilizing the 60 GHz frequency band, which are expected to take Wi-Fi speeds to multiple gigabits per second, and IEEE 802.1lax products, which are expected to improve the spectrum efficiency of Wi-Fi, thus enhancing system throughput per area in high-density scenarios of access points and client stations.

With seemingly limitless opportunities for new products and services, the proliferation of Wi-Fi continues to soar. Wi-Fi products can be deployed not only in apartments, but also in large corporations and campuses, and do everything from simple web browsing and peer-to-peer sharing to bandwidth-hungry and connectivity-demanding applications such as multimedia streaming and real-time teleconferencing, cable replacement, and wireless docking, to name a few. Coupled with the recent introduction of Wi-Fi CERTIFIED™ Passpoint, in which users can enjoy seamless and secure connectivity when roaming between cellular and Wi-Fi and between Wi-Fi networks, Wi-Fi devices now offer higher capacity and improved power management, and readily handle many demanding applications while paving the way for new products and services. Furthermore, the technology is now reaching beyond phones, PC networking, and consumer electronics into new sectors, such as the automotive industry and smart energy. According to Strategy Analytics 2012, Wi-Fi is now in over 25 percent of households, which is approximately 440 million people [1]. Furthermore, ABI Research recently increased its Wi-Fi shipment outlook and predicted that almost 3 billion Wi-Fi devices are expected to be shipped by 2015, which is nearly double the 1.5 billion devices shipped in 2012 [2].

The increasing popularity of Wi-Fi, combined with excellent market forecasts from reputable market research and intelligence firms, indicate that Wi-Fi is and will continue to be a key technology that is shaping the future of consumers and businesses worldwide. In response to this momentum of interest and popularity, our Feature Topic aims at providing a timely and concise reference to the state of the art, the latest research findings, and the future directions around Wi-Fi technologies.

An overwhelming number of papers were received for this Feature Topic, and five papers from a pool of high-quality submissions were selected based on their relevance to this Feature Topic and their technical merits. A number of good papers did not make the cut because of the above-mentioned criteria and the limitation of space. Nevertheless, we would like to thank all of the authors who submitted their work to this Feature Topic and all of our reviewers for their meticulous reviews, which were delivered in a timely fashion. In the following, we introduce the five articles by highlighting the contributions made therein. We hope our readers find these articles useful, not only in understanding the recent developments, but also for inspiring their own work.

Our Feature Topic begins with "Wi-Fi Could Be Much More" contributed by W. Sun *et al.* This article gives our readers an overview and high-level understanding of a number of recently released and ongoing specifications developed by IEEE 802.11 and the Wi-Fi Alliance. Furthermore, the authors have also outlined the most telling features and the corresponding advantages of these specifications, such as enhanced throughput, enlarged coverage, and ease of use.

Following a nice overview of these published and ongoing IEEE 802.11 specifications and the Wi-Fi Alliance CERTIFIED Passpoint program, the next two articles focus on architectural design and implementation challenges of WiGig technologies. First, Jo *et al.* present "Holistic Design Considerations for Environmentally Adaptive 60 GHz Beamforming Technology," which addresses the importance of considering an active adaptive beamforming algorithm that will be vital to accurately accommodate various surrounding environments for future 60 GHz applications. Then Rajagopal discusses an important topic that has yet to be well understood in the industry, power efficiency in future multiple gigabit Wi-Fi systems. In particular, the author presents a low-power architecture suitable for large-bandwidth Wi-Fi systems and discusses how the power efficiency challenge would be addressed.

The next two articles cover another very popular topic, the interworking of Wi-Fi and cellular systems. The first article is contributed by Kudo *et al.* and is titled "An Advanced Wi-Fi Data Service Platform Coupled with a Cellular Network for Future Wireless Access." Here, the authors present a Wi-Fi management architecture that utilize the potential capacity of Wi-Fi in the cellular network and provide high-grade user experience even in high-density Wi-Fi environments. In the second of these articles, "Enabling the Coexistence of LTE and Wi-Fi in Unlicensed Bands," Abinader *et al.* discuss performance issues that arise from concurrent operation of Wi-Fi and LTE in the same unlicensed bands from the radio resource management viewpoint. A few coexistence mechanisms and future research directions that may lead to a successful joint deployment of Wi-Fi and LTE are also presented.

REFERENCES

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[2] http://www.abiresearch.com/press/total-cumulative-wi-fi-enabled-device-shipments-re.

BIOGRAPHIES

EDWARD AU [SM] (edward.ks.au@gmail.com) is a senior staff member of Marvell Technology Group responsible for product certification and standardization of Wi-Fi and Bluetooth. He chairs a few technical task groups related to location, power saving, and smart grid technologies in the Wi-Fi Alliance and a study group on next generation 60 GHz in IEEE 802.11. He has a strong research record, having published tens of papers and patents. He also serves as Editor of various IEEE journals, and has served as a Track/Symposium Co-Chair of IEEE conferences. He is the receipt of the 2013 Top Editor Award of *IEEE Transactions on Vehicular Technology*.

MINHO CHEONG [SM] is a managing director at Newracom, Inc., ETRI's spin-off company which develops solutions for Korea Wi-Fi ecosystem. He has been a project leader, Special Fellow and head of delegates of IEEE 802 at ETRI, and worked on R&D on 4G systems, multi-gigabit-per-second nomadic system and next generation WLAN. He was the coordinator of Korea's standardization for next generation WLAN, Chair of VHT Working Group at TTA, and PHY Co-chair and Functional Requirements Editor of IEEE 802.11ac and IEEE 802.11ah. His research interests include OFDM, MIMO, and interference cancellation, on which he has filed over 100 patents. He and his group were named the "Nation-Wide Outstanding Research Group" by the Prime Minister of Korea in 2007. He was the recipient of the Silver Prize in Human-Tech. Thesis Contest in 2004 and the Grand Prize in the DSP Design Contest in 1997.

CHIU NGO [SM] is head of Standards and Technology Enabling, Samsung Electronics Silicon Valley R&D Center. As a senior director, he leads Samsung's U.S. standardization activities for consumer electronics. He received his Ph.D and B.Sc. (Honors) degrees in electrical engineering from the University of Southern California and the University of Hong Kong, respectively. He has actively participated in standardization organizations and holds Samsung's position on some Boards of Directors. He has co-authored more than 40 published papers and holds more than 150 U.S. patents. He is a Chartered Engineer of IET.

CARLOS CORDEIRO [SM] is a principal engineer in the Mobile and Communications Group within Intel Corporation. He is the overall lead of Intel's standardization programs in Wi-Fi and in the area of short-range multi-gigabits-per-second wireless systems using millimeter frequencies. In the Wi-Fi Alliance, he is a member of the Board of Directors and serves as the Technical Advisor, in addition to chairing the technical task group on 60 GHz. He was the Technical Editor of the IEEE 802.11ad standard. Due to his contributions to wireless communications, he received several awards including the prestigious Global Telecom Business 40 under 40 in 2012 and 2013, the IEEE Outstanding Engineer Award in 2011, and the IEEE New Face of Engineering Award in 2007. He is the co-author of two textbooks on wireless published in 2006 and 2011, has published about 100 papers in the wireless area alone, and holds over 30 patents. He has served as an Editor of various journals.

WEIHUA ZHUANG [F] has been with the University of Waterloo, Canada, since 1993, where she is a professor and a Tier I Canada Research Chair in Wireless Communication Networks. Her current research focuses on resource allocation and QoS provisioning in wireless networks, and on smart grid. She is a co-recipient of several best paper awards from IEEE conferences. She was the Editor-in-Chief of *IEEE Transactions on Vehicular Technology* (2007–2013), and Technical Program Symposia Chair of IEEE GLOBECOM 2011. She is a Fellow of the Canadian Academy of Engineering and the Engineering Institute of Canada, and an elected member of the Board of Governors and VP Mobile Radio of the IEEE Vehicular Technology Society. She was an IEEE Communications Society Distinguished Lecturer from 2008 to 2011.