

SECOND EDITION

Mobile Positioning and Tracking

From Conventional to
Cooperative Techniques

Simone Frattasi | Franciscantonio Della Rosa


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MOBILE POSITIONING AND TRACKING

... to my dear dad, Luigi, and my grandad, Francesco
Simone Frattasi

... to my lovely wife Anna, my mom Emilia, my dad Liberto and my
brother Gianluca
Francescantonio Della Rosa

About the Authors

Simone Frattasi became European Patent Attorney (EPA) in 2016. He received his PhD in wireless and mobile communications from Aalborg University (AAU), Aalborg, Denmark, in 2007, and his MSc degree *cum laude* and his BSc degree in telecommunications engineering from the University of Rome “Tor Vergata”, Italy, in 2002 and 2001, respectively. Additionally, he obtained a certificate as a project manager from Act2Learn in 2009 and a certificate as an instructor in the IEEE Leadership Course from the IEEE in 2008.

He is the head of the Patent Section at Sony Mobile Communications, Lund, Sweden, where he was previously employed as a senior patent attorney. From 2011 to 2015, he worked as a patent consultant at Patrade. From 2010 to 2011, he worked as a postdoc in the Center for TeleInfrastruktur (CTIF) at AAU, where he was technical project manager for the FP7 project ASPIRE, proposal coordinator for the SOS-4-HEALTH project (including AAU, Aalborg Hospital, Telenor, Care4All, IctalCare, and G4S) and lecturer for the course “IPR, Patenting and Technology Transfer” for the M.Sc. on innovative communication techniques and entrepreneurship. In 2009, he worked as a patent consultant in Plougmann & Vingtoft. From 2007 to 2008, he worked as a postdoc at AAU, where he was technical project manager for the industrial project LA-TDD, a collaboration with Nokia Siemens Networks (NSN). From 2005 to 2007, he fundraised and worked as a manager for the Danish-funded project COMET at AAU. From 2002 to 2005, he worked as a research assistant at AAU on two FP5 projects (STRIKE and VeRT) and one industrial project (JADE) in collaboration with the Global Standards & Research Team, Samsung Electronics, Korea.

He is author of the first edition of the book *Mobile Positioning and Tracking: from Conventional to Cooperative Techniques* (John Wiley & Sons Inc., June 2010). He is author/co-author of more than 65 publications, including papers published in journals, magazines and proceedings of international conferences, book chapters, encyclopedia papers and technical reports. He is inventor/co-inventor of one US patent and four Danish patent applications. He has served as a reviewer for several technical and IPR journals (including the *Oxford Journal of Intellectual Property Law & Practice*), magazines and international conferences, and as a guest editor for several special issues in various technical journals and magazines. He has been an instructor for a half-day tutorial on wireless location at IEEE PIMRC’07 as well as for seminars and tutorials on IPR at MobileHCI’15 and GWS’14.

He was co-founder of Kyranova Ltd, and co-founder and president of the International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL), the International Conference on Cognitive Radio and Advanced Spectrum Management (CogART) and One2One (Business & Science Match).

He is an editorial board member of the journal *Recent Advances in Communications and Networking Technology* (formerly *Recent Patents in Telecommunications*, Benthamscience Publishers). He has been a board member of IPR Nord, Chairman of the Danish Section of IEEE Graduates of the Last Decade (GOLD) and a member of the IEEE Aerospace & Electronic Systems Society.

His research interests include (but are not restricted to) cooperation in wireless networks, link layer techniques, wireless location, quality of service mechanisms, next-generation wireless services and architectures, user perspectives and sociological dimensions related to the evolution of technology and society.

Francescantonio Della Rosa received an MSc degree in electrical and electronic engineering from Aalborg University, Denmark, a BSc degree in telecommunications engineering from the University of Cassino, Cassino, Italy, and is a PhD candidate at Tampere University of Technology, Tampere, Finland.

He is an accredited business coach for the European Commission at Horizon 2020 SME Instrument, also serving as chairman at Ekin Labs Oy (Finland). Currently he is the managing director of Technological Innovation at Radiomaze Inc (California), funded by Singularity University Labs and selected to solve the Global Grand Challenges for Humanity in the Security sector at NASA Ames Research Park in Mountain View (USA).

He has successfully coached and instructed more than 20 technology-based ventures, turning research ideas and results into products and businesses.

Francescantonio served as IEEE Finland Section Executive Board Officer and as Honorary Jury at CES 2017 for Space and UAV Category. He funded and managed multi-million euro projects focusing on the commercialization of innovative solutions for business, security, IoT, the space industry, big data, artificial intelligence, such as the EU FP7 Multi-technology Positioning Professionals Marie Curie and the European FP7 project GRAMMAR (Galileo Ready Advanced Mass Market Receiver), leading the team who built the first Galileo receiver for the mass market. He has also commercialization research and development results and the Watchdog project, realizing the first home security solution that can detect a human presence based on the radio wave fluctuations in conventional wifi systems available in domestic environments.

He is the winner of many of international research, innovation and business awards as a result of the commercialization of his research results, for example the CES 2015 Innovation Award Honoree, Las Vegas, Best European Startup 2015 in the Smart Spaces category at EIT Digital, Best Technology Transfer Awards Hipeac Network of Excellence and the NOKIA Foundation Award. He also gained an Entrepreneurial Achievement award from Kauffman FastTrac TechVenture, which grants the bearer the right and responsibility to build an “un-common company”, and received the nomination as Young Research Entrepreneur of the Year 2016 in Finland and the Honorary Technical Creativity and Business Award from Tampere City (Finland).

He is co-author and editor of three books and many chapters, patents and scientific publications focusing his research interests of positioning and navigation, GNSS, location-based services, big data, IoT, wireless communications, artificial intelligence, business and innovation.

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Preface

Localization is a research topic that is receiving increasing attention from both academia and industry. Previously considered as vital information for vehicle tracking and military strategy, location information has now been introduced into wireless communication networks. In contrast to dedicated solutions, such as the global positioning system (GPS), that were designed to simply provide positioning information, the new solutions for wireless networks are able to supply the combined benefit of both communication and positioning. As a consequence, the network operator, as well as the service provider and the end user, can profit from such position-enabled communication capabilities. Indeed, while the network operator is able to manage the resources of its network more efficiently, the service provider is able to offer location-based services to the end user, who can fully enjoy such personalized location-dependent services. In particular, it can be found from the literature that location information is being used as a basic requirement for the deployment of new protocols (e.g., routing and clustering), new technologies (e.g., cooperative systems) and new applications (e.g., navigation and location-aware advertising). From the point of view of the industry, the use of location information has been stimulated mainly by applications such as navigation, location-dependent searching and social networking. Since wireless communication networks are nowadays present anywhere and anytime, every location-dependent networking enhancement, service or application can be spread rapidly and used globally.

The above-mentioned trends are a major stimulator for the development of novel solutions for obtaining positioning information in wireless networks. Chapter 1 outlines the motivation behind these solutions and presents potential categories and applications of location-based services (both conventional and network-related).

Chapter 2 introduces the main application areas for positioning, providing an overview of the localization ecosystem and its usability with a look at the main patent trends. Chapter 3 presents the fundamentals of wireless communications for positioning, describing the main radio propagation characteristics of both conventional and cooperative. Chapter 4 presents the fundamentals of positioning, proposing a classification of positioning methods, techniques and main error sources. Chapter 5 describes these various types of data association algorithms, showing the advantages and disadvantages of each. Chapter 6 deals with the fundamentals of tracking, in particular several mobility models (including group-based and socially based models) that are used in the following chapters will be introduced. Chapter 7 considers some advanced techniques (from the realm of signal processing) used to mitigate the errors mentioned in previous chapters, thus trying to enhance the accuracy of the overall location estimation process. Chapter 8 presents the state of the art of satellite-based and terrestrial based

positioning systems, spanning the range from outdoor to indoor environments, from wide-area networks to short-range networks, and from orthogonal frequency division multiplexing to ultra-wideband (UWB) technologies. In Chapter 9 we introduce the topic of UWB positioning by describing fundamentals about regulations and positioning approaches for tracking targets. Chapter 10 presents indoor positioning approaches in wireless local area networks by highlighting the effect the environmental impairments and human body signal absorption have on signal strength measurements. Chapter 11 introduces the topic of multi-tag localization by adopting radio frequency identification systems and experimental activities as well. Replicating cooperative human behavior in wireless communications has resulted in a number of emerging research fields. In particular, its application in wireless location has flown in a new breed of techniques that may revolutionize the entire field. Hence, in Chapter 12 we take a tour through the state of the art of what we call “cooperative augmentation systems”, that is, mobile positioning systems that exploit the cooperation of users, terminals and networks to boost their location estimation accuracy in both simulated and real environments.

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List of Abbreviations

1L-DF	one-level data fusion
2D	two-dimensional
2L-DF	two-level data fusion
3D	three-dimensional
3G	third generation
3GPP	Third Generation Partnership Project
4G	fourth generation
5G	fifth generation
ACPS	Ad-Coop Positioning System
A-GNSS	Assisted Global Navigation Satellite System
A-GPS	Assisted Global Positioning System
ACK	acknowledge
ADC	analog-to-digital converter
AOA	angle of arrival
AP	access point
API	pplication programming interface
ASP	application service provider
AWGN	additive white Gaussian noise
B2B	business-to-business
B2C	business-to-consumer
BCCH	broadcast control channel
BF	beamforming
BPM	burst position modulation
BPSK	binary phase shift keying
BPZF	band-pass zonal filter
BS	base station
BTS	base transceiver station
CA	collision avoidance
CAS	cooperative augmentation system
CATV	cable television
CD	collision detection
CDF	cumulative distribution function
CDMA	code division multiple access
CEP	circular error probability

CH	cluster head
CID	cell ID
CG	cluster gateway
CIR	carrier-to-interference ratio
CLI	caller location information
CLS	constrained least squares
CM	cluster member
COFDM	coded orthogonal frequency division multiplexing
COMET	Cooperative Mobile Positioning System
coop-EKF	cooperative extended Kalman filter
coop-WNLLS	cooperative weighted nonlinear least squares
CR	cognitive radio
CRC	cyclic redundancy check
CRLB	Cramér–Rao lower bound
CRB	Cramér–Rao bound
CRMSE	cooperative root mean square error
CSMA	carrier sense multiple-access
CS-MNS	clock sampling–mutual network synchronization
CSN	connectivity service network
CTM	current transformation matrix
CTS	clear to send
CW	continuous wave
DAC	digital-to-analog converter
DAA	detection and avoidance
DGPS	Differential Global Positioning System
DL	downlink
DOP	dilution of precision
DP	direct path
DR	dead reckoning
DS	direct sequence
DSSS	direct-sequence spread spectrum
E911	enhanced 9-1-1
eCall	emergency call
ED	energy detector
EDGE	enhanced data rates for GSM evolution
EGNOS	European Geostationary Navigation Overlay Service
EIRP	effective isotropic radiated power
EKF	extended Kalman filter
e.m.	electromagnetic
EM	expectation maximization
EPS	evolved packet system
ERP	equivalent radiated power
EUWB	European ultra-wideband
FBMC	filter bank multicarrier
FCC	Federal Communications Commission
FDD	frequency division duplex