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Positioning and Navigation with Applications to Communications

Locating and tracking energy-emitting or reflecting sources is a prototypical signal processing problem that has attracted attention for over 60 years. Early applications were in radar and sonar and involved a small number of sensors, usually as few as two or three, employing correlation operations to make time-difference-of-arrival (TDOA) measurements. Such processing is inherently centralized, since a data collection point must be used to collect the TDOA measurements and translate them into a position estimate. Later, radar and sonar research focused on applications involving arrays of relatively closely spaced sensors where only local processing was required to form an estimate of the direction of arrival (DOA) of the received signals. While additional information would be required to actually locate the signal source, most of the driving applications involved line-of-sight (LOS) propagation, and a DOA estimate was usually sufficient.

The six decades of work in positioning have seen a considerable broadening of the techniques employed for localization as well as the applications where localization is important. Work has focused on exploitation of the temporal properties of the signals rather than just their spatial signature, including specialized wideband waveforms, higher order statistics, and space-time processing techniques that take into account Doppler effects to extract velocity information. More complicated environments in seismology and biomedicine require modeling reverberation, multipath, and non-LOS propagation effects. Satellite-based localization using the global positioning systems (GPSs), the Global Navigation Satellite System (GLONASS), and a number of augmentation overlays such as WAAS (Wide Area Augmentation System) and EGNOS (European Geostationary Navigation Overlay Service), has matured to the point that numerous products are available to the consumer at relatively little cost.

POSITIONING IN WIRELESS NETWORKS

Recently, some of the most interesting positioning application areas have emerged in wireless communications. The most prominent of these is the Federal Communications Commission (FCC) mandate, together with the European recommendation E112, that wireless providers be able to locate within tens of meters users who broadcast E911/E112 emergency calls. This has led to renewed interest in positioning problems, especially those requiring mitigation of non-LOS propagation and severe multipath. Two broad application areas have emerged. The first involves localization in outdoor scenarios, typically using a cellular-type network, like the E911 problem. The availability of multiple base stations means that processing is centralized and that long-range coverage can be achieved. Propagation environments can range from the benign, e.g., suburban or country-side locations with elevated cell towers, to highly complex dense urban settings. Power consumption is often not a critical issue at the user terminal in these applications, but cost is, so one cannot simply assume that GPS data is available for broadcast (even if it were, the problem of noncooperative localization of mobile cell phone signals will continue to be of interest in surveillance applications). The second application area centers on shorter range ad hoc networks, often indoors, where power conservation and intelligent resource management are critical. Processing is decentralized, and information must be shared in a cooperative, "multihop" fashion for the nodes in the network to locate both themselves and whatever it is external to the network that they are sensing. Complicated, non-LOS propagation is typically the rule in such situations. There are many "cross-over" applications as well, since centralized networks are also very common indoors (e.g., wireless LANs) and outdoor ad hoc networks are currently of great interest to the military.

IN THIS ISSUE

The wealth and variety of positioning problems in wireless networks make it a timely subject for a special section of *IEEE Signal Processing Magazine*. Out of the 45 papers submitted to this special section, five outstanding articles were chosen for publication based on their high quality and their broad coverage of the important aspects of the field. The first article, "Signal Processing Techniques in Network-Aided Positioning" by Sun et al., provides a broad, systems-level tutorial overview of both the cellular and ad hoc network localization problems as well as algorithms that have been proposed for both. "Network-Based Wireless Location" by Sayed et al. goes into greater detail for cellular applications (for both outdoor mobile and indoor wireless LAN scenarios), outlining the mathematics behind fusing TDOA and DOA measurements in

forming position estimates. A critical question in network localization systems like those designed to satisfy the FCC's E911 requirement is whether or not the desired accuracy is achievable given the level of uncertainty in the system's measurements (e.g., errors in determining signal strength and TDOA and DOA information). In "Mobile Positioning Using Wireless Networks," Gustafsson and Gunnarsson show how to address this issue by means of a theoretical performance analysis based on the Fisher Information Matrix.

From here, the focus shifts somewhat. In "Locating the Nodes," by Patwari et al., attention is directed towards determining the location of sensors in a distributed ad hoc network where perhaps only a few nodes know or are able to individually compute their positions. Cooperation and data sharing between sensors is required to form a network map from which resource allocation (e.g., routing, power consumption) decisions can be made. In most applications, location information is also needed for the data collected by the network to be meaningful. Ultra-wideband (UWB) signals are a promising candidate for use in networks such as these, especially in short-range indoor applications where high resolution, reduced interference, and propagation around obstacles is required. In the last article, "Localization via Ultra-Wideband Radios" by Gezici et al., techniques and performance limits are presented for positioning based on TDOA, DOA, and signal strength using UWB signals.

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We would like to acknowledge the many individuals who helped make this special section a reality. First of all, the reviewers' efforts have led to significant improvements in the quality of the published articles; we appreciate their careful and thorough reading of the authors' manuscripts. We commend the authors themselves, not only for providing well-written and informative articles but also for helping us keep with our aggressive publication timetable. Thanks are also due to Petar Djuric for helping us organize the special section and for working with IEEE to get it published. We hope that the articles contained in this issue will serve to increase awareness of and interest in this exciting field of research. SP