Towards Precise, Ubiquitous and Real-Time Positioning

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The advantages in signal/array processing and in hardware design have allowed Multiple Input Multiple Output (MIMO) and high bandwidth channels. These advantages result in unprecedented wireless system performances enabling not only high data rates but also accurate and reliable positioning. Positioning is currently an enabler for new applications in many fields, from healthcare to agriculture. WiFi and 5G are both integrating localization together with communication to fulfill the requirements of location-based services. However, many fields require strict needs in terms of accuracy (decimeter level), and latency (around 10ms), and the current WiFi and 5G positioning performance [1] cannot cope well with them. To fulfill these needs, novel signal processing algorithms are needed and they have to comply with three key requirements, as outlined below.

(1) Accuracy. Precise localization systems use signal processing algorithms to extract the Time of Flight (ToF) and the Angle of Arrival (AoA) of the direct path from the overall multipath channel to locate the target. Therefore, extracting the direct-path signal from a superimposed signal is not straightforward as they interfere with each other once they arrive at the receiver. For precise positioning, this path has to be extracted relatively free of interference from other paths

(2) Robustness. Moving obstacles, and pieces of furniture create Non Line of Sight (NLOS) areas making positioning considerably harder as the direct path is significantly weaker than reflected paths. Algorithms need to be robust against NLOS settings to provide accurate direct path resolvability, hence pervasive localization with the same level of accuracy as in clear Line of Sight (LOS) cases.

(3) Real-time. The positioning algorithms have to operate at a millisecond scale to meet tight time requirements.

We summarize below two main works that aim at fulfilling these three requirements.

Accurate and ubiquitous localization. We implement UbiLocate [2], a Wi-Fi location system that copes well with common AP deployment densities and works ubiquitously, i.e., without excessive degradation under NLOS. UbiLocate demonstrates that meter-level median accuracy NLOS localization is possible through (i) an innovative angle estimator based on a Nelder-Mead search, (ii) a fine-grained time of flight ranging system with nanosecond resolution, and (iii) the accuracy improvements brought about by the increase in bandwidth and the number of antennas of IEEE 802.11ac. In combination, they provide superior resolvability of multipath components, significantly improving location accuracy over prior work. We implement our location system on off-the-shelf 802.11ac devices. Our experimental evaluation shows an overall improvement in the localization performance by a factor of 2-3.

Multiband localization. Millimeter-wave (mmWave) offers high bandwidth and highly directional antennas which allow for unprecedented accuracy in wireless sensing and localization applications. We thoroughly analyze mmWave localization and find that it is either extremely accurate or has a very high error since there is significant mmWave coverage via reflections and even through walls. As a consequence, sub-6 GHz technology can not only provide (coarse) localization where mmWave is not available but is also critical to decide among multiple candidate antennas and APs for accurate mmWave localization. Based on these insights, we design MultiLoc [3] a high-accuracy joint mmWave and sub-6 GHz location system. We enable CSI-based angle estimation and FTM-based ranging on off-the-shelf mmWave devices to implement our mechanism and carry out an extensive measurement campaign. Our system is the first to achieve 18 cm median location error with off-the-shelf devices under their normal mode of operation.

Real-time positioning. Positioning systems usually carry out a multidimensional (each dimension corresponds to a path parameter) search to estimate the path parameters, i.e, the AoA and the ToF. This search is completely prohibited due to its high complexity. To efficiently solve this problem, the Space-Alternating Generalized Expectation-Maximization (SAGE) [4] algorithm carries out several 1D searches to estimate each parameter individually. However, this 1D search is done through a matrix by vector multiplication that has a complexity of $O(N^2)$, which still is not feasible for real-time. We significantly reduce the 1D search's time complexity to operate at a millisecond scale. We achieve a similar performance to the UbiLocate algorithm [2] but with much lower time complexity.

Conclusions. Positioning promises to enable new location-based services. However, the current WiFi and 5G protocols cannot deal with the hard requirements to be met to realise this promise. To deal with that, we have proposed a series of works to enable accurate, robust, and real-time positioning.

References

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