Title

Impact of the geometry of terrestrial network for positioning using ToA and AoA measurements

Abstract

Positioning with terrestrial telecommunication systems, such as digital TV (DVB-T [1],[2]) or mobile communication systems (4G [3],[4],[5]), has been a topic of research in the last recent years. These techniques usually employ modified synchronization techniques in order to compute a time-of-arrival (ToA) measurements from several emitters. This positioning technique requires solving the issue of emitter synchronization, which can be dealt with by synchronizing the emitter network or by estimating of the emitters' clock offsets by a monitoring station or within the mobile receiver.

The introduction of 5G in the coming years is also seen as favorable for positioning purpose based on TOA measurements due to increase signal bandwidth, but will also allow the possibility to use angle-of-arrival (AoA) measurements. Indeed, massive multiple-input multiple-output (MIMO) technology, based on the use of antenna arrays at the emitter and receiver side, is a prevalent feature of the 5G standard ([6],[7]) notably due to the higher carrier frequency used by the system, leading to a reduction of the antenna size and the possibility to use antenna arrays with many elements.

This paper does not deal with the signal processing required to obtain a ToA or AoA measurements, but rather focuses on the positioning algorithm using these measurements and the impact of the network geometry on the relative positioning accuracy. Relative positioning accuracy will provide guidance on the relative accuracy gain for different network geometries, measurement combinations or receiver locations compared to a reference point. The absolute positioning accuracy would require assumptions on the signal structure, the signal processing performed by the receiver, and the receiver/emitter hardware characteristics, which are very specific to particular system deployments. Only relative positioning accuracy will be evaluated in order to provide the impact of the emitters' network geometry for a large variety of systems. This relative accuracy analysis is similar to the analysis of the dilution of precision (DOP) factor for GNSS performance analysis, where the DOP is used to characterize the satellite geometry quality, without taking into account other error sources such as the one coming from the atmospheric propagation, receiver processing, multipath, interference, etc.

The paper will first introduce the (Weighted) Least Squares 2D positioning algorithm for ToA only, AoA only and ToA+AoA-based positioning. A simpler case will be first presented where the measurements' accuracy does not depend on the distance to the emitter. In a second time, a more complex case will be considered where the measurements' relative accuracy follows a logarithmic degradation with the distance. The formulas to obtain the 2D relative accuracy will be provided for all cases, and an illustration of the relative accuracy will be provided in a simplified scenario containing only 3 emitters.

The relative accuracy analysis will then be performed on larger emitter networks: first, on a theoretical hexagonal grid network, and then on the actual 4G emitter network deployed over Toulouse (for a single telecommunication operator and for all available operators). Different assumptions will be made on the availability of ToA and AoA measurements, and conclusions will be drawn on the expected impact of the network geometry for the different combinations of measurements.

References

[1] P. Thevenon, D. Serant, O. Julien, C. Macabiau, M. Bousquet, L. Ries and S. Corazza, "Positioning using mobile TV based on the DVB-SH standard", in Navigation : Journal of the Institute of Navigation, 2011, 58 (2), pp 71-90.

[2] L. Chen, P. Thevenon, G. Seco-Granados, O. Julien and H. Kuusniemi, "Analysis on the TOA Tracking With DVB-T Signals for Positioning", in IEEE Transactions on Broadcasting, vol. 62, no. 4, pp. 957-961, Dec. 2016. doi: 10.1109/TBC.2016.2606939

[3] J. A. del Peral-Rosado, J. A. López-Salcedo, G. Seco-Granados, F. Zanier and M. Crisci, "Achievable localization accuracy of the positioning reference signal of 3GPP LTE," *2012 International Conference on Localization and GNSS*, Starnberg, 2012, pp. 1-6. doi: 10.1109/ICL-GNSS.2012.6253127

[4] Xu, W., Huang, M., Zhu, C., and Dammann, A. (2016) Maximum likelihood TOA and OTDOA estimation with first arriving path detection for 3GPP LTE system. *Trans. Emerging Tel. Tech.*, 27: 339–356. doi: 10.1002/ett.2871.

[5] Shamaei, Kimia, Khalife, Joe, Kassas, Zaher M., "Comparative Results for Positioning with Secondary Synchronization Signal versus Cell Specific Reference Signal in LTE Systems," *Proceedings of the 2017 International Technical Meeting of The Institute of Navigation*, Monterey, California, January 2017, pp. 1256-1268.

[6] W. Roh *et al*., "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility and prototype results," in *IEEE Communications Magazine*, vol. 52, no. 2, pp. 106-113, February 2014. doi: 10.1109/MCOM.2014.6736750

[7] R. W. Heath, N. González-Prelcic, S. Rangan, W. Roh and A. M. Sayeed, "An Overview of Signal Processing Techniques for Millimeter Wave MIMO Systems," in *IEEE Journal of Selected Topics in Signal Processing*, vol. 10, no. 3, pp. 436-453, April 2016. doi: 10.1109/JSTSP.2016.2523924