











Fig. 6. Emitter location RMSE versus AOA standard deviation  $\sigma_{AOA}$ .

#### IV. CONCLUSION

In this paper we refined 3D AOA measurements processing model for positioning a transmitter with one stationary ground and one flying UAV based receiver station. Performed simulation results validate possibility to handle NLOS with just two stations, because even coarse AOA with  $\sigma_{AOA} < 10^\circ$  can contribute to NLOS measurements identifying.

#### REFERENCES

- [1] V. A. Mochalov and A. P. Pschenichnikov, "Functional scheme of the flying sensor networks architecture design," *2016 18th International Conference on Advanced Communication Technology (ICACT)*, Pyeongchang, 2016, pp. 659-663.
- [2] Y. Lee, Y. Lee, Y. Jang and M. Park, "A process-aware drone-equipped 3D engine and wireless control measurement platform for integrated management of SOC facilities," *2018 20th International Conference on Advanced Communication Technology (ICACT)*, Chuncheon, Gangwondo, Korea (South), 2018, pp. 1067-1072.
- [3] O. D. Saputra, M. Irfan, N. N. Putri and S. Y. Shin, "UAV-based localization for distributed tactical wireless networks using archimedean spiral," *2015 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, Nusa Dua, 2015, pp. 392-396.
- [4] D. Kim, K. Lee, M. Park and J. Lim, "UAV-Based Localization Scheme for Battlefield Environments," *MILCOM 2013 - 2013 IEEE Military Communications Conference*, San Diego, CA, 2013, pp. 562-567.
- [5] G. Stamatescu, D. Popescu and R. Dobrescu, "Cognitive radio as solution for ground-aerial surveillance through WSN and UAV infrastructure," *Proceedings of the 2014 6th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, Bucharest, 2014, pp. 51-56.
- [6] S. Waharte and N. Trigoni, "Supporting Search and Rescue Operations with UAVs," *2010 International Conference on Emerging Security Technologies*, Canterbury, 2010, pp. 142-147.
- [7] D. J. Torrieri, "Statistical Theory of Passive Location Systems," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-20, no. 2, pp. 183-198, March 1984.
- [8] M. Sivers, G. Fokin, P. Dmitriev, A. Kireev., D. Volgushev, A. Ali, "Indoor Positioning in WiFi and NanoLOC Networks," *Lecture Notes in Computer Science*, vol. 9870, pp. 465-476, 2016.
- [9] H.-J. Du and P. Y. Lee, "Passive Geolocation Using TDOA Method from UAVs and Ship/Land-Based Platforms for Maritime and Littoral Area Surveillance," Defense R and D, Ottawa, Canada, Technical Memorandum 2004-033, Feb. 2004.
- [10] H.-J. Du and P. Y. Lee, "Simulation of multi-platform geolocation using a hybrid TDOA-AOA method," Defense R and D Ottawa, Canada, Technical Memorandum 2004-256, Dec. 2004.
- [11] F. Fletcher, Branko Ristic and Darko Musicki, "Recursive estimation of emitter location using TDOA measurements from two UAVs," *2007 10th International Conference on Information Fusion*, Quebec, Que., 2007, pp. 1-8.
- [12] N. Okello, F. Fletcher, D. Musicki and B. Ristic, "Comparison of Recursive Algorithms for Emitter Localisation using TDOA Measurements from a Pair of UAVs," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 47, no. 3, pp. 1723-1732, July 2011.
- [13] A. H. A. Al-odhari, G. Fokin and A. Kireev, "Positioning of the radio source based on time difference of arrival method using unmanned aerial vehicles," *2018 Systems of Signals Generating and Processing in the Field of on Board Communications*, Moscow, 2018, pp. 1-5.
- [14] Fokin, G. A., Alodhari, A. H., "TDOA measurement processing for positioning using unmanned aerial vehicles," *T-Comm (Media Publisher)*, vol. 12, № 7, pp. 52-58, 2018.
- [15] D. Musicki, R. Kaune and W. Koch, "Mobile Emitter Geolocation and Tracking Using TDOA and FDOA Measurements," in *IEEE Transactions on Signal Processing*, vol. 58, no. 3, pp. 1863-1874, March 2010.
- [16] Z. Wang, E. Blasch, G. Chen, D. Shen, X. Lin and K. Pham, "A low-cost, near-real-time two-UAS-based UWB emitter monitoring system," in *IEEE Aerospace and Electronic Systems Magazine*, vol. 30, no. 11, pp. 4-11, November 2015.
- [17] M. A. Magers, "Geolocation of RF Emitters Using a Low-Cost UAV-Based Approach," M. Sci. thesis, Air Force Institute of Technology, Write-Patterson Air Force Base, Ohio, United States, 2016.
- [18] M. Hasanzade, O. Herekoglu, N. K. Ure, E. Koyuncu, R. Yeniceri and G. Inalhan, "Localization and tracking of RF emitting targets with multiple unmanned aerial vehicles in large scale environments with uncertain transmitter power," *2017 International Conference on Unmanned Aircraft Systems (ICUAS)*, Miami, FL, USA, 2017, pp. 1058-1065.
- [19] F. Koohifar, I. Guvenc and M. L. Sichitiu, "Autonomous Tracking of Intermittent RF Source Using a UAV Swarm," in *IEEE Access*, vol. 6, pp. 15884-15897, 2018.
- [20] Fokin G., Ali A.A.H., "Algorithm for Positioning in Non-line-of-Sight Conditions Using Unmanned Aerial Vehicles," *Lecture Notes in Computer Science*, vol. 11118, pp. 496-508, 2018.
- [21] G. Fokin, "TDOA Measurement Processing for Positioning in Non-Line-of-Sight Conditions," *2018 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom)*, Batumi, 2018, pp. 1-5.
- [22] Y. Wang and K. C. Ho, "An Asymptotically Efficient Estimator in Closed-Form for 3-D AOA Localization Using a Sensor Network," in *IEEE Transactions on Wireless Communications*, vol. 14, no. 12, pp. 6524-6535, Dec. 2015.
- [23] J. Yin, Q. Wan, S. Yang and K. C. Ho, "A Simple and Accurate TDOA-AOA Localization Method Using Two Stations," in *IEEE Signal Processing Letters*, vol. 23, no. 1, pp. 144-148, Jan. 2016.
- [24] K. Dogancay and G. Ibal, "Instrumental Variable Estimator for 3D Bearings-Only Emitter Localization," *2005 International Conference on Intelligent Sensors, Sensor Networks and Information Processing*, Melbourne, Australia, 2005, pp. 63-68.
- [25] L. Badrials, H. Kennedy and A. Finn, "Effects of coordinate system rotation on two novel closed-form localization estimators using azimuth/elevation," *Proceedings of the 16th International Conference on Information Fusion*, Istanbul, 2013, pp. 1797-1804.
- [26] R. Zekavat, R. M. Buehrer, *Handbook of position location: Theory practice and advances*, Wiley-IEEE Press, 2011.
- [27] G. Mashkov, E. Borisov and G. Fokin, "Experimental validation of multipoint joint processing of range measurements via software-defined radio testbed," *2017 19th International Conference on Advanced Communication Technology (ICACT)*, Bongpyeong, 2017, pp. 979-984.



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