

Energy Efficient 2D and 3D Localization in Wireless Sensor Networks using Single Anchor Node

*A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of*

*Doctor of Philosophy
in
(Electronics and Communication Engineering)*

by

Prateek Raj Gautam
(Reg. No.: 2016REL01)



DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
MOTILAL NEHRU NATIONAL INSTITUTE OF TECHNOLOGY ALLAHABAD,
PRAYAGRAJ, INDIA 211004
June 2021

Undertaking

I declare that the work presented in this thesis titled “*Energy Efficient 2D and 3D Localization in Wireless Sensor Networks using Single Anchor Node*”, submitted to the Department of Electronics and Communication Engineering, **Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India 211004**, for the award of the **Doctor of Philosophy** degree in **Department of Electronics and Communication Engineering**, is my original work. I neither have plagiarized any part of the thesis nor submitted the same work for the award of any other degree anywhere. In case this undertaking is found incorrect, the degree shall be withdrawn unconditionally.

Sign

Prateek Raj Gautam

(2016REL01)

PRAYAGRAJ

Certificate

This is to certify that the thesis entitled “**Energy Efficient 2D and 3D Localization in Wireless Sensor Networks using Single Anchor Node**” being submitted by **Prateek Raj Gautam** (registration number: 2016REL01) in the Electronics and Communication Engineering Department, Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India 211004, in fulfillment of the requirement for the award of the Doctor of Philosophy, is a record of bonafide work carried out by him, under my supervision. This work has not been submitted in parts or in full to any other university or institute for the award of any degree or diploma or for any other purpose.

Dr. Arvind Kumar

(Associate Professor)

Electronics and Communication Engineering Department

MNNIT Allahabad

Acknowledgment

The present doctoral thesis would not be possible without the support, encouragement, and contributions of so many remarkable individuals.

First and foremost, I would like to thank my supervisor **Dr. Arvind Kumar** (*Associate Professor, ECED, MNNIT Allahabad*). Without his guidance and dedicated involvement in every step throughout the process, this thesis would have never been accomplished. It's an honor and blessing to work under his supervision. I would like to thank you very much for your kind support and understanding. I would like to thank the members of my student research committee **Dr. Y. K. Prajapati** (*ECED, MNNIT Allahabad*), and **Prof. D. K. Yadav** (*CSED, MNNIT Allahabad*).

I am also extremely grateful to **Prof. Amit Dhawan** (*HOD ECED, MNNIT*), **Prof. Rajeev Tripathi** (*Director, MNNIT Allahabad*), **Dr. Manish Tiwari** (*Convenor DDPC, ECED, MNNIT Allahabad*), **Prof. Vijay Shankar Tripathi** (*ECED, MNNIT Allahabad*), and **Dr. Arun Prakash** (*ECED, MNNIT Allahabad*), for their sincere cooperation and continuous encouragement. I would like to thank the other respected faculty members and staff of ECED MNNIT Allahabad for their support in the fulfillment of the Ph.D. work.

Getting through my thesis required more than academic support, and I have many, many people to thank for listening to and, at times, having to tolerate me in the up and down in this journey. I cannot begin to express my gratitude and appreciation for their friendship. I also appreciate all the contributions from my friends and teammates **Tarique Rashid**, **Akshay Verma**, and especially **Sunil Kumar** for motivating me from time to time. For many memorable evenings out and in, I must thank everyone above as well as **Satya Prakash**, **Pushpender Gupta**, and **Vikrant Varhney**.

...

Sign

Prateek Raj Gautam



Abstract

Wireless Sensor Networks (WSNs) is a sub-class of wireless Ad-hoc networks where sensor nodes are randomly deployed to gather some specific type of information about physical phenomena such as temperature, pressure, humidity, rainfall, etc. The nodes in an ad-hoc network are small battery-operated devices with limited computational capabilities and transceivers to communicate with nearby nodes and the base station (BS) or a gateway to another network. However, in WSNs, these nodes also have additional sensor/transducer modules to measure some desired physical phenomena, hence, called sensor nodes or sensors. The lifetime of a WSN can be defined as the functional duration of nodes in WSNs. The lifetime of the network (or nodes in the network) depends on the initially installed battery and power consumption of the nodes. To prolong the lifetime of network operation like routing, sensing, communications protocols are planned differently.

...



Contents

Acknowledgment	vii
Abstract	ix
Table of contents	xii
List of figures	xiii
List of tables	xv
List of abbreviations	xvii
List of symbols	xix
1 How To Use thesisMNNIT class	1
1.1 REMOVE After Finalizing	1
1.2 how to compile	1
1.2.1 customize texworks	2
1.3 \documentclass [Final or Draft]{ thesisMNNIT }	2
1.4 to print author	3
1.5 Figure and figure ref	3
1.6 Cite and footcite	3
1.7 make Index list as	3
1.8 Define glossary and abbreviations	3
List of publications	5

Bibliography	15
Index	17
Author biography	19



List of Figures

1.1	mnnitlogo	3
-----	---------------------	---



List of Tables



List of abbreviations

abbreviation Abb.

rss received signal strength indicator.

WSN Wireless sensor network.



List of symbols

P_t Power transmit.



Chapter 1

How To Use thesisMNNIT class

1.1 REMOVE After Finalizing

to remove this chapter remove comment \printHelp from the template file

1.2 how to compile

It uses biber (insted of bibtex) for bibliography compilation.

It is a six step process and the sequence is

1. pdflatex
2. biber
3. makeindex
4. makeglossaries
5. pdflatex
6. pdflatex

1.2.1 customize texworks

go to texworks edit preferences typesetting processing tools

add makeglossaries to compiler

go to texworks edit preferences typesetting processing tools

click + to add new name makeglossaries browse to texlive bin directory where makeglossaries is located in the parameters add \$basename and save

create custom after analyzing other scripts

Use this script to compile on linux or bash shell. similar sequence of commands can be used on windows.

1. pdflatex \$1 \$2 \$3
2. biber \$2
3. makeindex -s \$2
4. makeglossaries \$2
5. pdflatex \$1 \$2 \$3
6. pdflatex \$1 \$2 \$3

here \$1 \$2 \$3 requires in arguments \$filename, \$basename and \$synctexoptions

1.3 \documentclass [Final or Draft]{ thesisMNNIT }

You can use Draft option to compile chapter and bib only, Final option will compile all front matter and backmatter

1.4 to print author

`\printAuthorWithSign`

`\printAuthorSign`

`\theauthor`

1.5 Figure and figure ref



Figure 1.1: mnnitlogo

1.6 Cite and footcite

The Figure 1.1 default [1], [2]¹ margins produced by small TEXT normalize TEXT

1.7 make Index list as

`\index{Prateek} \index{Raj} \index{Refresh}`

1.8 Define glossary and abbreviations

Define abbreviations as below and list will be generated Define definition

¹2.

`\abbDef{WSN}{Wireless Sensor Network}`

Define short form

`\abb{Definition}{Short form, ABB, ot term}`

Define short form for glosary but do not print

`\abbNoPrint{ P_t }{Power transmit}`

`\abbDef{rssi}{received signal strength indicator}`

`\abb{Wireless Sensor Network}{WSN}`

`\abb{ABB}{abbreviation}`

`\abb{ P_t }{Power transmit}`

results as received signal strength indicator (rssi)

Wireless Sensor Network (WSN)

ABB (abbreviation)

Separate list of symbols with `\sym`

`\sym{Power transmit}{ P_t }{pt} Power transmit (P_t)`

To print use above defined terms use code as glossary package

`\gls{WSN}`

`\glspl{ABB}`

results appear as WSN rssi

List of publications

Journals

- 1) **P. R. Gautam et al.**, “Energy-efficient localization of sensor nodes in WSNs using beacons from rotating directional antenna”, *IEEE Transactions on Industrial Informatics*, vol. 15, no. 11, pp. 5827–5836, 2019
DOI: 10.1109/TII.2019.2908437, **Impact Factor:** 9.112
- 2) **P. R. Gautam et al.**, “Energy-efficient localization of sensor nodes in WSNs using single beacon node”, *IET Communications*, vol. 14, no. 9, pp. 1459–1466, 2020
DOI: 10.1049/iet-com.2019.1298, **Impact Factor:** 2.1
- 3) **P. R. Gautam et al.**, “Energy-efficient three dimensional localization in WSNs using directional beacons from single anchor node”, *IEEE Wireless Communications*, 2021 **Under review**
- 4) **P. R. Gautam et al.**, “Industrial inventory monitoring with 3D localization of sensors in wireless sensor nodes”, *IEEE Sensor Journal*, 2021 **Under review**
- 5) **P. R. Gautam et al.**, “Directional antenna design for experimentation in internet of things and wireless sensor networks”, *IEEE Antenna and Wireless Propagation Letter*, 2021 **Under review**

Conferences and Book chapters

- 1) **P. R. Gautam et al.**, “Localization of Sensor Nodes in WSNs using Three Dimensional Angle of Arrival detection at BS”, in *2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, IEEE, Nov. 2019, pp. 1–4
DOI: 10.1109/UPCON47278.2019.8980262
- 2) **P. R. Gautam et al.**, “Localization of sensor nodes in WSN using area between a node and two beacons”, in *Advances in VLSI, Communication, and Signal Processing*, ser. Lecture Notes in Electrical Engineering, Springer, 2020, pp. 221–228
DOI: 10.1007/978-981-32-9775-3_22
- 3) **P. R. Gautam et al.**, “Sensor localization in WSNs using rotating directional - antenna at the base station”, in *Advances in VLSI, Communication, and Signal Processing*, ser. Lecture Notes in Electrical Engineering, vol. 683, Springer, 2021, pp. 705–718
DOI: 10.1007/978-981-15-6840-4_58

Bibliography

- [9] **P. R. Gautam**, S. Kumar, A. Verma, and A. Kumar, “Angle of arrival localization in wsns without array antenna at the target node”, *IEEE Transactions on Industrial Informatics*, 2021.
- [10] **P. R. Gautam**, S. Kumar, A. Verma, and A. Kumar, “Angle of arrival localization in wsns without array antenna at the target”, *IEEE Transaction on Aerospace and Electronic Systems*, 2021.
- [11] H. S. AbdelSalam and S. Olariu, “Towards enhanced rssi-based distance measurements and localization in wsns”, in *IEEE INFOCOM Workshops 2009*, IEEE, 2009, pp. 1–2.
- [12] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: A survey”, *Computer networks*, vol. 38, no. 4, pp. 393–422, 2002.
- [13] N. A. Ali, M. Drieberg, and P. Sebastian, “Deployment of MICAz mote for wireless sensor network applications”, in *2011 IEEE International Conference on Computer Applications and Industrial Electronics (ICCAIE)*, 2011, pp. 303–308.
- [14] M. Amarlingam, P. Rajalakshmi, V. kumar Netad, M. Yoshida, and K. Yoshihara, “Centroid based 3D localization technique using RSSI with a mobile robot”, in *2014 International Symposium on Wireless Personal Multimedia Communications (WPMC)*, IEEE, 2014, pp. 391–395.
- [15] I. Amundson and X. D. Koutsoukos, “A survey on localization for mobile wireless sensor networks”, in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 5801 LNCS, 2009, pp. 235–254.
- [16] G. Ausiello, P. Crescenzi, G. Gambosi, *et al.*, *Complexity and approximation: Combinatorial optimization problems and their approximability properties*. Springer Science & Business Media, 2012, pp. 3–10.
- [17] N. Bnilam, E. Tanghe, J. Steckel, W. Joseph, and M. Weyn, “ANGLE: ANGular Location Estimation Algorithms”, *IEEE Access*, vol. 8, pp. 14 620–14 629, 2020.
- [18] A. Boukerche, H. A. Oliveira, E. F. Nakamura, and A. A. Loureiro, “Localization systems for wireless sensor networks”, *IEEE wireless Communications*, vol. 14, no. 6, pp. 6–12, 2007.
- [19] X. Cai, P. Wang, L. Du, *et al.*, “Multi-objective three-dimensional DV-Hop localization algorithm with NSGA-II”, *IEEE Sensors Journal*, vol. 19, no. 21, pp. 10 003–10 015, 2019.
- [20] L. Chelouah, F. Semchedine, and L. Bouallouche-Medjkoune, “Localization protocols for mobile wireless sensor networks: A survey”, *Computers & Electrical Engineering*, vol. 71, pp. 733–751, Oct. 2018.

- [21] M. Chen, X. Ding, X. Wang, and X. Xu, "A novel three-dimensional localization algorithm based on DV-HOP", in *2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)*, IEEE, 2014, pp. 70–73.
- [22] L. Cheng, C. Wu, Y. Zhang, *et al.*, "A survey of localization in wireless sensor network", *International Journal of Distributed Sensor Networks*, vol. 2012, 2012.
- [23] P. Y. Chiang, P. C. P. Chao, D. C. Tarng, and C. Y. Yang, "A novel wireless photoplethysmography blood-flow volume sensor for assessing arteriovenous fistula of hemodialysis patients", *IEEE Transactions on Industrial Electronics*, vol. 64, no. 12, pp. 9626–9635, Dec. 2017.
- [24] T. J. Chowdhury, C. Elkin, V. Devabhaktuni, D. B. Rawat, and J. Oluoch, "Advances on localization techniques for wireless sensor networks: A survey", *Computer Networks*, vol. 110, pp. 284–305, 2016.
- [25] F. Chraim, Y. B. Erol, and K. Pister, "Wireless gas leak detection and localization", *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, pp. 768–779, Apr. 2016.
- [26] F. Chraim, Y. B. Erol, and K. Pister, "Wireless gas leak detection and localization", *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, pp. 768–779, 2016.
- [27] F. Chraim, Y. B. Erol, and K. Pister, "Wireless gas leak detection and localization", *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, pp. 768–779, 2016.
- [28] W. Cui, L. Zhang, B. Li, *et al.*, "Received-signal-strength based indoor positioning using random vector functional link network", *IEEE Transactions on Industrial Informatics*, vol. PP, no. 99, pp. 1–1, 2017.
- [29] W. Cui, L. Zhang, B. Li, *et al.*, "Received-signal-strength based indoor positioning using random vector functional link network", *IEEE Transactions on Industrial Informatics*, vol. PP, no. 99, pp. 1–1, 2017.
- [30] R. Dagher and R. Quilez, "Localization in wireless sensor networks", *Wireless Sensor and Robot Networks: From Topology Control to Communication Aspects*, pp. 203–247, 2013.
- [31] V. Dakulagi, "A new approach to achieve a trade-off between direction-of-arrival estimation performance and computational complexity", *IEEE Communications Letters**IEEE Communications Letters*, vol. 7798, no. c, pp. 5–9, 2020.
- [32] V. Dakulagi and J. He, "Improved direction-of-arrival estimation for modified symmetric sensor array", *IEEE Sensors Journal*, no. c, pp. 1–1, 2020.
- [33] K. Derr and M. Manic, "Wireless sensor networks—node localization for various industry problems", *IEEE Transactions on Industrial Informatics*, vol. 11, no. 3, pp. 752–762, Jun. 2015.
- [34] F. A. El-Qawasma, T. M. Elfouly, and M. H. Ahmed, "Minimising number of sensors in wireless sensor networks for structure health monitoring systems", *IET Wireless Sensor Systems*, vol. 9, no. 2, pp. 94–101, 2019.
- [35] A. F. G. Ferreira, D. M. A. Fernandes, A. P. Catarino, and J. L. Monteiro, "Localization and positioning systems for emergency responders: A survey", *IEEE Communications Surveys Tutorials*, vol. 19, no. 4, pp. 2836–2870, Fourthquarter 2017.
- [36] L. Gui, M. Yang, P. Fang, and S. Yang, "Rss-based indoor localisation using mdcf", *IET Wireless Sensor Systems*, vol. 7, no. 4, pp. 98–104, 2017.
- [37] E. Hamouda and A. S. Abohamama, "Wireless sensor nodes localiser based on sine–cosine algorithm", *IET Wireless Sensor Systems*, vol. 10, no. 4, pp. 145–153, 2020.

- [38] G. Han, J. Jiang, C. Zhang, *et al.*, “A survey on mobile anchor node assisted localization in wireless sensor networks”, *IEEE Communications Surveys Tutorials*, vol. 18, no. 3, pp. 2220–2243, 2016.
- [39] G. Han, J. Jiang, C. Zhang, *et al.*, “A survey on mobile anchor node assisted localization in wireless sensor networks”, *IEEE Communications Surveys Tutorials*, vol. 18, no. 3, pp. 2220–2243, 2016.
- [40] G. Han, H. Xu, T. Q. Duong, J. Jiang, and T. Hara, “Localization algorithms of wireless sensor networks: A survey”, *Telecommunication Systems*, vol. 52, no. 4, pp. 2419–2436, 2013.
- [41] T. V. Haute, B. Verbeke, E. D. Poorter, and I. Moerman, “Optimizing time-of-arrival localization solutions for challenging industrial environments”, *IEEE Transactions on Industrial Informatics*, vol. 13, no. 3, pp. 1430–1439, Jun. 2017.
- [42] T. V. Haute, B. Verbeke, E. D. Poorter, and I. Moerman, “Optimizing time-of-arrival localization solutions for challenging industrial environments”, *IEEE Transactions on Industrial Informatics*, vol. 13, no. 3, pp. 1430–1439, Jun. 2017.
- [43] Y. He, A. Behnad, and X. Wang, “Accuracy analysis of the two-reference-node angle-of-arrival localization system”, *IEEE Wireless Communications Letters*, vol. 4, no. 3, pp. 329–332, Jun. 2015.
- [44] J. F. Huang, G. Y. Chang, and G. H. Chen, “A historical-beacon-aided localization algorithm for mobile sensor networks”, *IEEE Transactions on Mobile Computing*, vol. 14, no. 6, pp. 1109–1122, 2015.
- [45] J. F. Huang, G. Y. Chang, and G. H. Chen, “A historical-beacon-aided localization algorithm for mobile sensor networks”, *IEEE Transactions on Mobile Computing*, vol. 14, no. 6, pp. 1109–1122, 2015.
- [46] M. Farooq-I-Azam, Q. Ni, and E. A. Ansari, “Intelligent energy efficient localization using variable range beacons in industrial wireless sensor networks”, *IEEE Transactions on Industrial Informatics*, vol. 12, no. 6, pp. 2206–2216, Dec. 2016.
- [47] M. Farooq-I-Azam, Q. Ni, and E. A. Ansari, “Intelligent energy efficient localization using variable range beacons in industrial wireless sensor networks”, *IEEE Transactions on Industrial Informatics*, vol. 12, no. 6, pp. 2206–2216, Dec. 2016.
- [48] Z. Iqbal, K. Kim, and H. N. Lee, “A cooperative wireless sensor network for indoor industrial monitoring”, *IEEE Transactions on Industrial Informatics*, vol. 13, no. 2, pp. 482–491, Apr. 2017.
- [49] S. Jabbar, M. Z. Aziz, A. A. Minhas, and D. Hussain, “A novel power tuning anchors localization algorithm for mobile wireless sensor nodes”, in *2010 10th IEEE International Conference on Computer and Information Technology*, 2010, pp. 2441–2446.
- [50] V. Kanwar and A. Kumar, “DV-Hop-based range-free localization algorithm for wireless sensor network using runner-root optimization”, *The Journal of Supercomputing*, Jul. 2020.
- [51] L. Karim, Q. H. Mahmoud, N. Nasser, A. Anpalagan, and N. Khan, “Localization in terrestrial and underwater sensor-based m2m communication networks: Architecture, classification and challenges”, *International Journal of Communication Systems*, vol. 30, no. 4, e2997, 2017, e2997 DAC.2997.
- [52] K. Katsaros, M. Dianati, R. Tafazolli, and X. Guo, “End-to-end delay bound analysis for location-based routing in hybrid vehicular networks”, *IEEE Transactions on Vehicular Technology*, vol. 65, no. 9, pp. 7462–7475, Sep. 2016.

- [53] F. Khelifi, A. Bradai, M. L. Kaddachi, and P. Rawat, "Design and experimental implementation of monitoring system in wireless sensor networks", *IET Wireless Sensor Systems*, vol. 8, no. 6, pp. 350–359, 2018.
- [54] P. Kułakowski, J. Vales-Alonso, E. Egea-López, W. Ludwin, and J. García-Haro, "Angle-of-arrival localization based on antenna arrays for wireless sensor networks", *Computers & Electrical Engineering*, vol. 36, no. 6, pp. 1181–1186, 2010.
- [55] S. Kumar and D. K. Lobiyal, "An advanced DV-Hop localization algorithm for wireless sensor networks", *Wireless Personal Communications*, vol. 71, no. 2, pp. 1365–1385, Jul. 2013.
- [56] J. Kumari, P. Kumar, and S. K. Singh, "Localization in three-dimensional wireless sensor networks: A survey", *The Journal of Supercomputing*, vol. 75, no. 8, pp. 5040–5083, Aug. 2019.
- [57] C. Laoudias, A. Moreira, S. Kim, *et al.*, "A survey of enabling technologies for network localization, tracking, and navigation", *IEEE Communications Surveys & Tutorials*, vol. 20, no. 4, pp. 3607–3644, 2018.
- [58] Y. Li, K. Yan, Z. He, *et al.*, "Cost-effective localization using rss from single wireless access point", *IEEE Transactions on Instrumentation and Measurement*, vol. 69, no. 5, pp. 1860–1870, 2019.
- [59] Libelium.com, *Wasp mote is a sensor device to develop internet of things projects*, 2020.
- [60] G. Liu, H. Chen, X. Sun, and R. C. Qiu, "Modified MUSIC algorithm for DOA estimation with nyströmapproximation", *IEEE Sensors Journal*, vol. 16, no. 12, pp. 4673–4674, 2016.
- [61] J. Luo, J. Hu, D. Wu, and R. Li, "Opportunistic routing algorithm for relay node selection in wireless sensor networks", *IEEE Transactions on Industrial Informatics*, vol. 11, no. 1, pp. 112–121, Feb. 2015.
- [62] J. Luo, J. Hu, D. Wu, and R. Li, "Opportunistic routing algorithm for relay node selection in wireless sensor networks", *IEEE Transactions on Industrial Informatics*, vol. 11, no. 1, pp. 112–121, Feb. 2015.
- [63] S. Maqbool and U. Sabeel, "Arising issues in wireless sensor networks: Current proposals and future developments", *IOSR Journal of Computer Engineering (Engineering)*, vol. 8, no. 6, pp. 2278–8727, Mar. 2013.
- [64] A. Naguib, "Multilateration localization for wireless sensor networks", *Indian Journal of Science and Technology*, vol. 13, no. 10, pp. 1213–1223, 2020.
- [65] O. Oguejiofor, A. Aniedu, H. Ejiofor, and A. Okolibe, "Trilateration based localization algorithm for wireless sensor network", *International Journal of Science and Modern Engineering (IJISME)*, vol. 1, no. 10, pp. 2319–6386, 2013.
- [66] O. O. Ogundile and A. S. Alfa, "A Survey on an Energy-Efficient and Energy-Balanced", *Sensors*, vol. 17, no. 5, pp. 10 841–51, 2017.
- [67] S. L. Omirou and A. C. Nearchou, "A cnc machine tool interpolator for surfaces of cross-sectional design", *Robotics and Computer-Integrated Manufacturing*, vol. 23, no. 2, pp. 257–264, 2007.
- [68] C. Ou, "A localization scheme for wireless sensor networks using mobile anchors with directional antennas", *IEEE Sensors Journal*, vol. 11, no. 7, pp. 1607–1616, Jul. 2011.
- [69] C. H. Ou and K. F. Ssu, "Sensor position determination with flying anchors in three - dimensional wireless sensor networks", *IEEE Transactions on Mobile Computing*, vol. 7, no. 9, pp. 1084–1097, 2008.

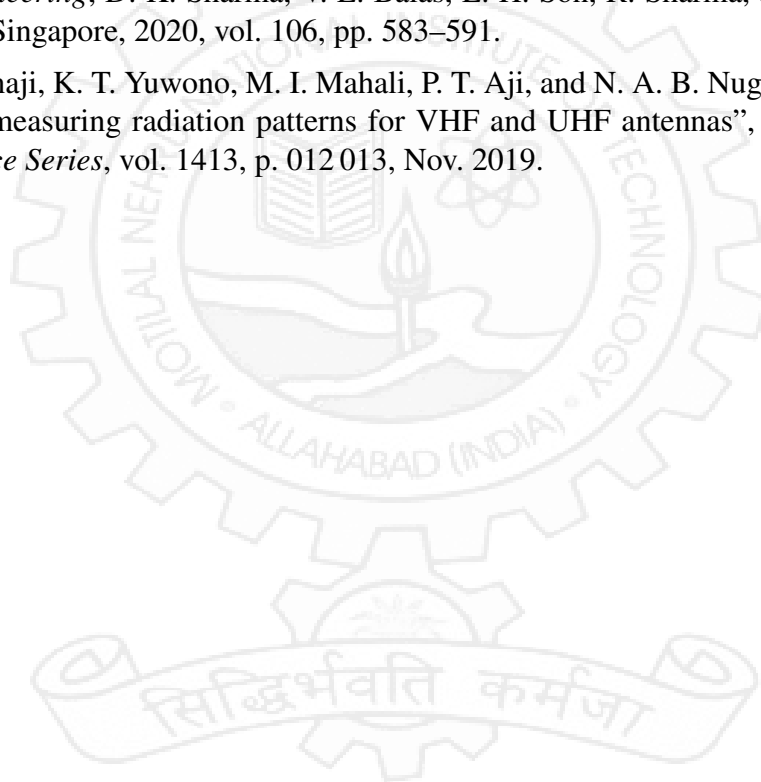
- [70] J. M. Pak, C. K. Ahn, Y. S. Shmaliy, and M. T. Lim, "Improving reliability of particle filter-based localization in wireless sensor networks via hybrid particle/fir filtering", *IEEE Transactions on Industrial Informatics*, vol. 11, no. 5, pp. 1089–1098, 2015.
- [71] J. M. Pak, C. K. Ahn, Y. S. Shmaliy, and M. T. Lim, "Improving reliability of particle filter-based localization in wireless sensor networks via hybrid particle/fir filtering", *IEEE Transactions on Industrial Informatics*, vol. 11, no. 5, pp. 1089–1098, 2015.
- [72] O. J. Pandey and R. M. Hegde, "Cooperative localisation over small world wsn using optimal allocation of heterogeneous nodes", *IET Wireless Sensor Systems*, vol. 8, no. 4, pp. 162–169, 2018.
- [73] N. A. Pantazis, S. A. Nikolidakis, and D. D. Vergados, "Energy-efficient routing protocols in wireless sensor networks: A survey", *IEEE Communications Surveys Tutorials*, vol. 15, no. 2, pp. 551–591, 2013.
- [74] N. A. Pantazis, S. A. Nikolidakis, and D. D. Vergados, "Energy-efficient routing protocols in wireless sensor networks: A survey", *IEEE Communications Surveys Tutorials*, vol. 15, no. 2, pp. 551–591, 2013.
- [75] A. K. Paul and T. Sato, "Localization in wireless sensor networks: A survey on algorithms, measurement techniques, applications and challenges", *Journal of Sensor and Actuator Networks*, vol. 6, no. 4, 2017.
- [76] S. G. Pease, P. P. Conway, and A. A. West, "Hybrid ToF and RSSI real-time semantic tracking with an adaptive industrial internet of things architecture", *Journal of Network and Computer Applications*, vol. 99, pp. 98–109, 2017.
- [77] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks categories and subject descriptors", *Proceedings of the 2nd international conference on Embedded networked sensor systems*, pp. 95–107, 2004.
- [78] I. Qasim, N. Habib, U. Habib, Q. F. Usman, and M. Kamal, "Comparison of localization algorithms for unmanned aerial vehicles", in *Intelligent Technologies and Applications*, I. S. Bajwa, T. Sibalija, and D. N. A. Jawawi, Eds., Singapore: Springer Singapore, 2020, pp. 258–269.
- [79] A. Rashid, Y. Tripathi, A. Prakash, and R. Tripathi, "Load aware energy-balanced data gathering approach in CRSNs", *IET Wireless Sensor Systems*, vol. 9, no. 3, pp. 143–150, 2019.
- [80] B. Risteska Stojkoska, "Nodes localization in 3d wireless sensor networks based on multi-dimensional scaling algorithm", *International scholarly research notices*, vol. 2014, 2014.
- [81] B. Risteska Stojkoska, "Nodes localization in 3D wireless sensor networks based on multi-dimensional scaling algorithm", *International scholarly research notices*, vol. 2014, 2014.
- [82] B. Risteska Stojkoska, "Nodes localization in 3D wireless sensor networks based on multi-dimensional scaling algorithm", *International scholarly research notices*, vol. 2014, 2014.
- [83] J. Saraswat and P. P. Bhattacharya, "Effect of duty cycle on energy consumption in wireless sensor networks", *International Journal of Computer Networks & Communications*, vol. 5, no. 1, p. 125, 2013.
- [84] R. Schmidt, "Multiple emitter location and signal parameter estimation", *IEEE Transactions on Antennas and Propagation*, vol. 34, no. 3, pp. 276–280, Mar. 1986.
- [85] Z. Sheng, C. Mahapatra, C. Zhu, and V. C. M. Leung, "Recent advances in industrial wireless sensor networks toward efficient management in IoT", *IEEE Access*, vol. 3, pp. 622–637, 2015.

- [86] C.-Y. Shih and P. J. Marrón, “COLA: complexity-reduced trilateration approach for 3D localization in wireless sensor networks”, in *2010 Fourth International Conference on Sensor Technologies and Applications*, IEEE, Jul. 2010, pp. 24–32.
- [87] R. C. Shit, S. Sharma, D. Puthal, *et al.*, “Ubiquitous localization (UbiLoc): a survey and taxonomy on device free localization for smart world”, *IEEE Communications Surveys & Tutorials*, vol. 21, no. 4, pp. 3532–3564, 2019.
- [88] R. C. Shit, S. Sharma, D. Puthal, and A. Y. Zomaya, “Location of things (LoT): a review and taxonomy of sensors localization in IoT infrastructure”, *IEEE Communications Surveys and Tutorials*, vol. 20, no. 3, pp. 2028–2061, 2018.
- [89] V. Srivastava, J. Neel, A. B. MacKenzie, *et al.*, “Using game theory to analyze wireless ad hoc networks”, *IEEE Communications Surveys & Tutorials*, vol. 7, no. 4, pp. 46–56, 2005.
- [90] K.-F. Ssu, C.-H. Ou, and H. C. Jiau, “Localization with mobile anchor points in wireless sensor networks”, *IEEE Transactions on Vehicular Technology*, vol. 54, no. 3, pp. 1187–1197, 2005.
- [91] K.-F. Ssu, C.-H. Ou, and H. C. Jiau, “Localization with mobile anchor points in wireless sensor networks”, *IEEE Transactions on Vehicular Technology*, vol. 54, no. 3, pp. 1187–1197, 2005.
- [92] S. Tomic, M. Beko, and R. Dinis, “3-D target localization in wireless sensor networks using RSS and AoA measurements”, *IEEE Transactions on Vehicular Technology*, vol. 66, no. 4, pp. 3197–3210, Apr. 2017.
- [93] S. Tomic, M. Beko, R. Dinis, and L. Bernardo, “On Target Localization Using Combined RSS and AoA Measurements”, *Sensors*, vol. 18, no. 4, p. 1266, Apr. 2018.
- [94] S. Tomic, M. Beko, R. Dinis, and P. Montezuma, “Distributed algorithm for target localization in wireless sensor networks using RSS and AoA measurements”, *Pervasive and Mobile Computing*, vol. 37, no. February 2018, pp. 63–77, 2017.
- [95] L. A. Villas, D. L. Guidoni, and J. Ueyama, “3d localization in wireless sensor networks using unmanned aerial vehicle”, in *2013 IEEE 12th International Symposium on Network Computing and Applications*, IEEE, 2013, pp. 135–142.
- [96] L. Wan, G. Han, L. Shu, S. Chan, and T. Zhu, “The application of DOA estimation approach in patient tracking systems with high patient density”, *IEEE Transactions on Industrial Informatics*, vol. 12, no. 6, pp. 2353–2364, Dec. 2016.
- [97] L. Wan, G. Han, L. Shu, S. Chan, and T. Zhu, “The application of doa estimation approach in patient tracking systems with high patient density”, *IEEE Transactions on Industrial Informatics*, vol. 12, no. 6, pp. 2353–2364, Dec. 2016.
- [98] L. Wan, G. Han, L. Shu, S. Chan, and T. Zhu, “The application of DOA estimation approach in patient tracking systems with high patient density”, *IEEE Transactions on Industrial Informatics*, vol. 12, no. 6, pp. 2353–2364, 2016.
- [99] J. Wang, Q. Gao, Y. Yu, X. Zhang, and X. Feng, “Time and energy efficient tof-based device-free wireless localization”, *IEEE Transactions on Industrial Informatics*, vol. 12, no. 1, pp. 158–168, Feb. 2016.
- [100] J. Wang, Q. Gao, Y. Yu, X. Zhang, and X. Feng, “Time and energy efficient tof-based device-free wireless localization”, *IEEE Transactions on Industrial Informatics*, vol. 12, no. 1, pp. 158–168, Feb. 2016.
- [101] J. Wang, R. K. Ghosh, and S. K. Das, “A survey on sensor localization”, *Journal of Control Theory and Applications*, vol. 8, no. 1, pp. 2–11, 2010.

- [102] J. C. Wang, C. H. Lin, E. Siahaan, B. W. Chen, and H. L. Chuang, "Mixed sound event verification on wireless sensor network for home automation", *IEEE Transactions on Industrial Informatics*, vol. 10, no. 1, pp. 803–812, Feb. 2014.
- [103] J. C. Wang, C. H. Lin, E. Siahaan, B. W. Chen, and H. L. Chuang, "Mixed sound event verification on wireless sensor network for home automation", *IEEE Transactions on Industrial Informatics*, vol. 10, no. 1, pp. 803–812, Feb. 2014.
- [104] W. Wang, X. Liu, M. Li, Z. Wang, and C. Wang, "Optimizing node localization in wireless sensor networks based on received signal strength indicator", *IEEE Access*, vol. 7, pp. 73 880–73 889, 2019.
- [105] X. Wang, "Multicast for 6lowpan wireless sensor networks", *IEEE Sensors Journal*, vol. 15, no. 5, pp. 3076–3083, May 2015.
- [106] X. Wang, Y. Liu, Z. Yang, K. Lu, and J. Luo, "Robust component-based localization in sparse networks", *IEEE Transactions on Parallel and Distributed Systems*, vol. 25, no. 5, pp. 1317–1327, 2014.
- [107] X. Wang, Y. Liu, Z. Yang, K. Lu, and J. Luo, "Robust component-based localization in sparse networks", *IEEE Transactions on Parallel and Distributed Systems*, vol. 25, no. 5, pp. 1317–1327, 2014.
- [108] Y. Wang and K. C. Ho, "Unified near-field and far-field localization for AOA and hybrid AOA-TDOA positionings", *IEEE Transactions on Wireless Communications*, vol. 17, no. 2, pp. 1242–1254, Feb. 2018.
- [109] A. Ward, A. Jones, and A. Hopper, "A new location technique for the active office", *IEEE Personal communications*, vol. 4, no. 5, pp. 42–47, 1997.
- [110] F. Wen and C. Liang, "Fine-grained indoor localization using single access point with multiple antennas", *IEEE Sensors Journal*, vol. 15, no. 3, pp. 1538–1544, 2015.
- [111] F. Wen and C. Liang, "Fine-grained indoor localization using single access point with multiple antennas", *IEEE Sensors Journal*, vol. 15, no. 3, pp. 1538–1544, 2015.
- [112] A. Wessels, X. Wang, R. Laur, and W. Lang, "Dynamic indoor localization using multilateration with RSSI in wireless sensor networks for transport logistics", *Procedia Engineering*, vol. 5, pp. 220–223, 2010.
- [113] D. Wu, D. Chatzigeorgiou, K. Youcef-Toumi, and R. Ben-Mansour, "Node localization in robotic sensor networks for pipeline inspection", *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, pp. 809–819, Apr. 2016.
- [114] D. Wu, D. Chatzigeorgiou, K. Youcef-Toumi, and R. Ben-Mansour, "Node localization in robotic sensor networks for pipeline inspection", *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, pp. 809–819, Apr. 2016.
- [115] D. Wu, D. Chatzigeorgiou, K. Youcef-Toumi, and R. Ben-Mansour, "Node localization in robotic sensor networks for pipeline inspection", *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, pp. 809–819, 2016.
- [116] M. Wu, N. Xiong, and L. Tan, "Adaptive range-based target localization using diffusion gauss-newton method in industrial environments", *IEEE Transactions on Industrial Informatics*, vol. 15, no. 11, pp. 5919–5930, Nov. 2019.
- [117] L. Xu, K. Wang, Y. Jiang, *et al.*, "A study on 2D and 3D weighted centroid localization algorithm in wireless sensor networks", in *2011 3rd International Conference on Advanced Computer Control*, IEEE, 2011, pp. 155–159.

- [118] Y. Xu, Y. Zhuang, and J.-j. Gu, "An Improved 3D Localization Algorithm for the Wireless Sensor Network", *International Journal of Distributed Sensor Networks*, vol. 11, no. 6, p. 315 714, Jun. 2015.
- [119] F. Yaghoubi, A. A. Abbasfar, and B. Maham, "Energy-efficient rssi-based localization for wireless sensor networks", *IEEE Communications Letters*, vol. 18, no. 6, pp. 973–976, 2014.
- [120] J. Yan, M. Zhou, and Z. Ding, "Recent advances in energy-efficient routing protocols for wireless sensor networks: A review", *IEEE Access*, vol. 4, pp. 5673–5686, 2016.
- [121] J. Yan, M. Zhou, and Z. Ding, "Recent advances in energy-efficient routing protocols for wireless sensor networks: A review", *IEEE Access*, vol. 4, pp. 5673–5686, 2016.
- [122] G. Yang, L. Xie, M. Mäntysalo, *et al.*, "A health-iot platform based on the integration of intelligent packaging, unobtrusive bio-sensor, and intelligent medicine box", *IEEE transactions on industrial informatics*, vol. 10, no. 4, pp. 2180–2191, 2014.
- [123] A. Yassin, Y. Nasser, M. Awad, *et al.*, "Recent advances in indoor localization: A survey on theoretical approaches and applications", *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 1327–1346, 2017.
- [124] A. Yassin, Y. Nasser, M. Awad, *et al.*, "Recent advances in indoor localization: A survey on theoretical approaches and applications", *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 1327–1346, 2016.
- [125] H. Zhang, Y. Liang, W. Zhang, *et al.*, "Improved PSO-based method for leak detection and localization in liquid pipelines", *IEEE Transactions on Industrial Informatics*, vol. PP, no. 99, pp. 1–1, 2018.
- [126] H. Zhang, Y. Liang, W. Zhang, *et al.*, "Improved PSO-based method for leak detection and localization in liquid pipelines", *IEEE Transactions on Industrial Informatics*, vol. PP, no. 99, pp. 1–1, 2018.
- [127] J. Zhang and J. Lu, "Analytical evaluation of geometric dilution of precision for three-dimensional angle-of-arrival target localization in wireless sensor networks", *International Journal of Distributed Sensor Networks*, vol. 16, no. 5, May 2020.
- [128] Q. Zhang, J. Huang, J. Wang, *et al.*, "A new centralized localization algorithm for wireless sensor network", Sep. 2008, pp. 625–629.
- [129] R. Zhang, J. Liu, X. Du, B. Li, and M. Guizani, "Aoa-based three-dimensional multi-target localization in industrial WSNs for LOS conditions", *Sensors*, vol. 18, no. 8, p. 2727, Aug. 2018.
- [130] Y. Zhang, Y. Chen, and Y. Liu, "Towards unique and anchor-free localization for wireless sensor networks", *Wireless Personal Communications*, vol. 63, no. 1, pp. 261–278, Mar. 2012.
- [131] Y. Zhang, Y. Lou, Y. Hong, and L. Xie, "Distributed projection-based algorithms for source localization in wireless sensor networks", *IEEE Transactions on Wireless Communications*, vol. 14, no. 6, pp. 3131–3142, 2015.
- [132] J. Zheng, C. Wu, H. Chu, and Y. Xu, "An improved RSSI measurement in wireless sensor networks", *Procedia engineering*, vol. 15, pp. 876–880, 2011.
- [133] K. Zheng, H. Wang, H. Li, *et al.*, "Energy-efficient localization and tracking of mobile devices in wireless sensor networks", *IEEE Transactions on Vehicular Technology*, vol. 66, no. 3, pp. 2714–2726, 2017.

- [134] X. Zheng, Z. Cai, J. Li, and H. Gao, "A study on application-aware scheduling in wireless networks", *IEEE Transactions on Mobile Computing*, vol. 16, no. 7, pp. 1787–1801, 2016.
- [135] Y. Zheng, J. Liu, M. Sheng, *et al.*, "Toward practical access point deployment for angle-of-arrival based localization", *IEEE Transactions on Communications*, vol. 6778, no. c, pp. 1–14, 2020.
- [136] H. M. A. Fahmy, "Protocol stack of wsns", in *Wireless Sensor Networks: Concepts, Applications, Experimentation and Analysis*. Singapore: Springer Singapore, 2016, pp. 55–68.
- [137] A. Verma, S. Kumar, P. R. Gautam, T. Rashid, and A. Kumar, "Fuzzy logic based effective clustering of homogeneous wireless sensor networks for mobile sink", *IEEE Sensors Journal*, vol. 20, no. 10, pp. 5615–5623, 2020.
- [138] B. Kranth, G. Dilip, and K. Kumar, "Planar patch antenna for 2.4 ghz wireless applications", *IOSR Journal of Electronics and Communication Engineering*, vol. 9, pp. 61–64, Jan. 2014.
- [139] N. L. Nhlengethwa and P. Kumar, "Microstrip patch antenna with enhanced gain for 2.4 GHz wireless local area network applications", in *Micro-Electronics and Telecommunication Engineering*, D. K. Sharma, V. E. Balas, L. H. Son, R. Sharma, and K. Cengiz, Eds. Springer Singapore, 2020, vol. 106, pp. 583–591.
- [140] E. Marpanaji, K. T. Yuwono, M. I. Mahali, P. T. Aji, and N. A. B. Nugraha, "Experimental study of measuring radiation patterns for VHF and UHF antennas", *Journal of Physics: Conference Series*, vol. 1413, p. 012013, Nov. 2019.



Index

Prateek, 3

Raj, 3

Refresh, 3



Author biography



Prateek Raj Gautam received B.Tech. degree in Electronics and Communication Engineering from University Institute of Engineering and Technology, Chattrapati Sahu Ji Maharaj University, Kanpur, India in 2008 and M.Tech. degree in Electronics and Communication Engineering from Harcourt Butler Technological Institute Kanpur, India in 2011. He has submitted this thesis for the award of a Ph.D. degree in Electronics and Communication Engineering from Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. His research interest includes energy-efficient schemes for wireless sensor networks, image processing, CDMA, IDMA, and brain wave mapping.

ORCID: **0000-0002-2889-4275**
SCOPUS: **57194277572**
PUBLONS: **I-9311-2017**
IEEE: **91250146**
E. Mail: **prateekrajgautam@gmail.com**

Tracing pages for hardbound cover. Print only if required.

tracking for side text of hard bound
cover to be print with front cover page

Ph.D. Thesis	Energy Efficient 2D and 3D Localization in Wireless Sensor Networks using Single Anchor Node	Prateek Raj Gautam	Jun 2021
--------------	--	--------------------	----------

Energy Efficient 2D and 3D Localization in Wireless Sensor Networks using Single Anchor Node

*A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of*

*Doctor of Philosophy
in
(Electronics and Communication Engineering)*

by

Prateek Raj Gautam
(Reg. No.: 2016REL01)



DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
MOTILAL NEHRU NATIONAL INSTITUTE OF TECHNOLOGY ALLAHABAD,
PRAYAGRAJ, INDIA 211004
June 2021

