Analytic Study on Object Localization Systems

Mohanad J. Ahmed[1], Mohammed Najm Abdullah[2]

[1, 2]Department of Computer Engineering, University of Technology, Iraq

Abstract: ***The concept of localization in wireless sensor networks refers to finding locations of sensors and use this information while reporting events. There are a number of nodes that already aware of their position (known as Beacons); they support other blind nodes to know their locations through localization techniques. It is infeasible to supply every node with GPS due to a large number of nodes and high cost and GPS is not functioning indoor, thus the localization techniques must find alternative ways to supply nodes with their locations. The location information is useful in making decisions. Each localization algorithm, hardware, and architecture is suitable for a specific application. Some of these applications work indoor as well as outdoor. This paper presents an analytical study of several algorithms and performance measure that used to locate the sensor nodes and also review some applications and simulators for these algorithms.***

Keywords: WSN, localization, survey, analytic, simulator, algorithm

1. Introduction

Wireless sensor networks are one of the most widely used applications in recent decades due to its importance in monitoring and reporting events such as an earthquake, tsunami, etc., this information is not useful without knowing their location. There has been a dramatic increase in the use of sensors since they are embedded and spread in numerous everyday devices as a part of pervasive computing. For example, smartphones are becoming popular and digital computing in some form is now an integral part of numerous applications [21]. Sensors became widely used through these devices and enabled to be interactive with people more friendlily such as Radio Frequency Identification (RFID) [3], [30]. The spreading of sensors is a big issue since it decides what localization algorithm, hardware, and software used to find the location information of the sensors. Because of errors in TOA and RSSI distance measurements [31], the localization precision will be the main evaluation criteria for localization algorithms [22]. The blind nodes determine their locations locally using a certain location computation technique with the assist of beacon nodes. The range-free and range-based localization algorithms techniques are most commonly used algorithms for location computation. Some of the applications are avoiding the use of GPS because of its high power consumption and cost and try to find alternatives [4] [23] [26]. Due to the unavoidable measure errors, the blind node cannot get its position accurately. Therefore the localization precision is one of the most important evaluation criteria for a localization algorithm [22]. The aim of this paper is to provide a comparison of various localization techniques with some analytical results from several experiments and differentiate between several algorithms metrics. The next sections of the paper are organized as follows: Sec 2 will consider the classification of localization systems, sect 3 shows architectures of localization systems, while the localization process steps are in sec 4, then localization algorithms in sec 5, sec 6 shows various performance metric, sec 7 is the protocols. Sec 8 and 9 are applications and simulators respectively and lastly sec 10 the conclusion.

2. Classification of object localization systems

Object localization system can be classified into two categories “range-based” and “range-free” localization [14], in addition, there are other types of classifications that may be used according to the needs and environment of operations these are:

1) Range-free and range-based algorithms [26]. (also in [29] the classification is further divided into fully range based and hybrid range-based localization)
   i. Range-based, measure the distances or the angles between nearby sensors (transmitter and receiver), some of these technologies are:
      a) Time of Arrival (ToA).
         - One way ToA [1].
         - Two ways ToA [1].
      b) Time Difference of Arrival (TDoA) [33].
         - Use two sources different in propagation speed.
      c) Received Signal Strength Indicator (RSS).
         - Taking the attenuation with respect to the distance between source and destination, the distance can be estimated. [2].
      d) The Angle of Arrival (AOA).
   ii. Range-free, which the sensors try to determine their positions lean only on the positions of anchors. No measure distance or angle used and depend on hop size, some of these technologies are: [39].
      a) Centroid.
      b) DV-HOP [2].
      c) Amorphous [40] [24].
      d) MDS.
      e) APIT.
2) Centralized and distributed algorithms [5] [32].
   a) Centralized, a central server solves the problem of the computation limitations of a single node, a base station is connected to all nodes and performs the calculations. The global information achieves high accuracy. [26]
   b) Distributed, internodes performs the calculation and communicate with each other, the energy consumption will be less than the centralized algorithm but with less computational power
3) Anchor-based and Anchor free algorithms [5], [26].
   a) Anchor-based.

- Anchor node is also known (beacon node) is a location awareness node, the location information is set either using a GPS system or manually pre-programmed during deployment. [26]
- Non-anchor nodes are identified using a localization algorithm with the assist of known beacon-nodes.
- Performance improved when more anchors are added to the network.
- Provides more accurate results than the anchor-free scheme.

b) Anchor free.

- Do not use any anchor nodes [27] [26].
- Nodes communicate with each other to estimate relative locations instead of computing absolute locations.

4) Mobile and fixed anchor/node [34].
   - Fixed beacon and fixed sensor.
   - Mobile beacon and fixed sensor.
   - Fixed beacon and mobile sensor.
   - Mobile beacon and mobile sensor.
5) Indoor and outdoor [6].
   - Some systems are dedicated for outdoor use such as those equipped with GPS, and some of these applications are not using GPS.
   - Affected by multipath and non-line-of-sight components of the signal [4].
6) Above ground/underwater.
7) GPS-based and GPS-free [7].
   - The GPS-based method known to be a high cost when inserting a GPS component in every node (infeasible solution) although the high accuracy of localization.
   - The GPS-free algorithms, avoid integration with GPS devices, soothe information location is collected from other resources, for further details refer to [6].
8) Coarse-grained and fine-grained [35].

a) Coarse-grained.

- Approximate the node coordination in the network.
- Provide a lower precision estimate to these coordinates.
- Coarse-grained do not use the received signal strength.

b) Fine-grained.

- Very precise coordinates and high communication computations are required.
- When using received signal strength algorithms we get fine-grained results.

The literature [8], [9], [5], and [10] show many different types of classifications Figure 0:1 in wireless sensor networks localization.

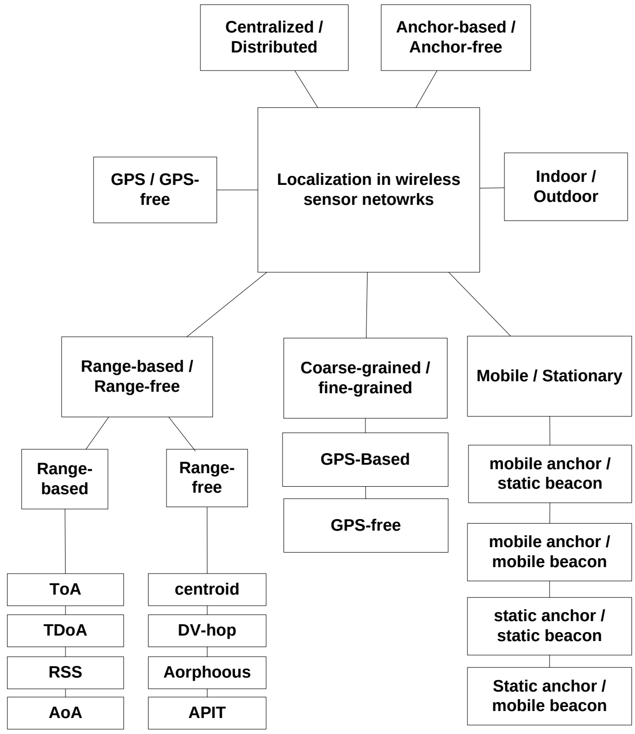

Figure 0:1 Localization of wireless sensor networks

3. The Architecture of Object Localization Systems

Localization system divided into three components Figure 3:1 [11]:

1) Position computation, the distance computation information relies on what is available on the anchor nodes.
2) Distance/angle estimation, the obtained distance/angle information are used by localization algorithms for estimating the location of nodes.
3) Localization algorithm, manipulate information of position and distance/angle to estimate nodes positions.

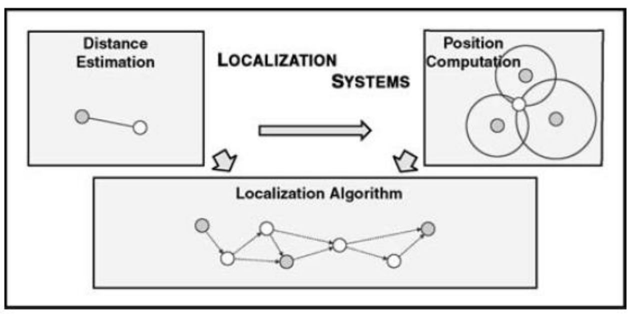

Figure 3:1 Architecture of localization system

Another method [12] shows the localization method in two-steps[3] Figure 3:2, while Figure 3:3 [7] shows another positioning system.

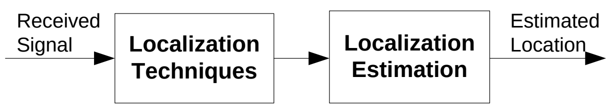

Figure 3:2: Two-Step localization system

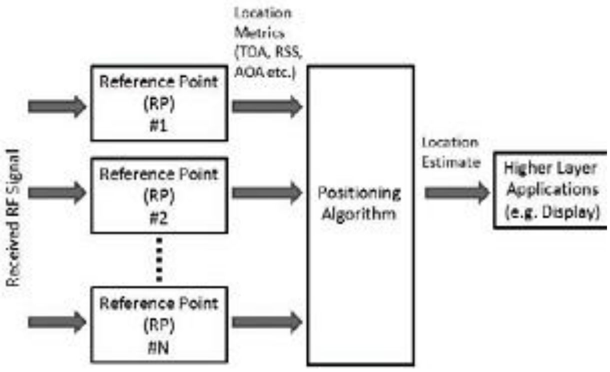

Figure 3:3 High-level architecture of a typical positioning system

3.1 Localization process

Localization schemes have two steps [29] as shown in Figure 0:1.

a) Distance-angle estimation.
Range-based techniques used to estimate the distance and angle between sensor nodes: TDOA, TOA, RSSI, AOA, and Hop-count.

b) Position computation.
Estimating the position of unknown nodes based on what is known about distance and angle obtained from the distance/angle estimation step these techniques are Lateration, triangulation, Bonding box, Probabilistic approach, and Fingerprinting.

Figure 0:1 Localization Process [13].

3.2 Localization algorithms

a) Triangulation [39], requires two known location nodes are used to localize one node using the AOA technique as shown in Figure 0:2(b) [14].
b) Trilateration, the node has distance measurements between its neighbors as shown in Figure 0:2(a). Each distance measurement forms a circle with a radius equal to the measurement on which node should lie around the neighborhood. Three circles intersection for three nonlinear neighbors defines the node location. [14]

3.3 Multilateration [39], [14]

Use the maximum likelihood (ML) estimation methods from multiple neighbor nodes for distance measurements; the difference is minimized between the estimated distances and distance measurements to find node location. The Multilateration resulting in the accurate position more than Trilateration because information from more beacons is taken by the blind node to calculate its coordinates, thus this type of algorithms is more suitable for GPS were using more than three satellites in the sky [15].

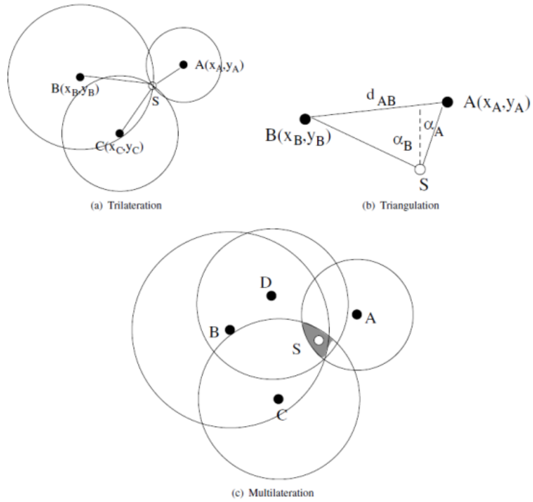

Figure 0:2 Range-based localization technique

3.4 Performance metrics

The performance of the localization techniques needs to be evaluated through various metrics according to the use and what certain values are used to tune the performance.
In this section, we outline some evaluation metrics [3]:

Performance

a) Accuracy: known as localization error or distance error.
b) The average or median distance error is adopted as a performance metric.
c) The better location technique comes from better accuracy. It can be used for evaluating the overall performance localization technique.
d) More errors rate means less accuracy and less reliable connection [26].
e) Precision: the success probability of position estimation with respect to the predefined accuracy, in some work defined as the standard deviation of the localization error or the geometric dilution of precision (GDOP).
f) Cumulative distribution function (CDF) of the localization error is used for measuring the precision of an indoor localization system [37].
g) Robustness: nodes should function normally even if some signals are corrupted or new patterns of RSS arrived.
h) Complexity: hardware architecture, algorithm computation, human intervention efforts.
i) Stability: measures changes in location estimation when some nodes are moved.
j) Hardware cost: deals with the hardware size.
k) Increasing hardware cost means adding more hardware.
l) Cost: in terms of hardware, computation, and communication.
m) Power consumption: the power consumption may increase due to excessive processing of data [26].
n) Error rate: comes in terms of the accuracy of localization [26].

3.5 Range-based and range-free algorithms

The range-based localization algorithm obtains high accuracy and requires more hardware components than the range-free localization (

Table 0-1) which obtains lower accuracy and lower hardware requirements. The centralized algorithms are more accurate than distributed algorithms but cost more hardware and communication overhead. Increasing the number of beacons increase the accuracy of calculations [5].

Table 0-1: Range-based and range-free localization algorithms

Localization Algorithms	Modus Operandi	Accuracy	Hardware Cost	Computation Cost	Communication Cost
Range Based	Distance Based	Median	Low	Low	—
	- RSSI				
	- TDoA	High	High	Low	—
	Angle Based				
	–AoA	High	High	Low	—
Range Free	Hop Count Based	Median	Low	Median	—
	–Per hop distance				
	Neighborhood Based Techniques				
	–Single neighbor	Low	Low	Low	—
	–Multi neighbor	Low	Low	Low	—
Centralized	—	High	—	High	High
Distributed	—	Median	—	Median	Low
Beacon Based	—	High	Very High	—	—
Beacon Free	—	Median	Very Low	—	—

3.6 Received signal strength

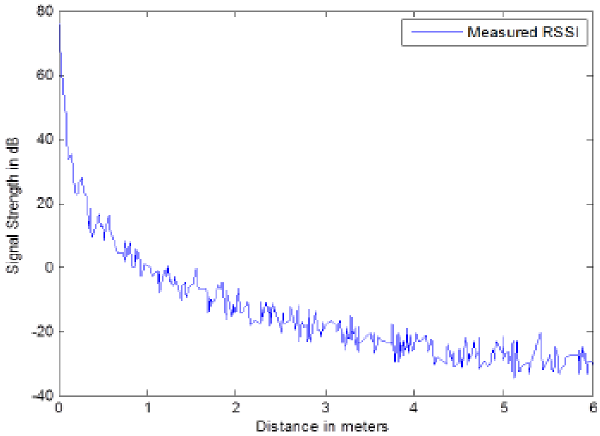

Figure 0:1 Received signal strength versus distance

Received signal strength degrades as the distance increase [5].

3.7 Cost analysis (RSSI, GPS, TOA, DV-hop)

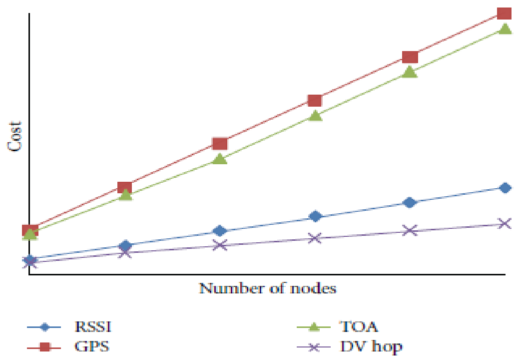

Figure 0:2 Cost analysis of localization techniques

TOA- and GPS-based systems are more expensive as compared to RSSI and DV hop [7].

3.8 The accuracy of different localization mechanisms

GPS systems are highly accurate, as compared to TOA, RSSI, and DV hop respectively [7], Figure 0:3.

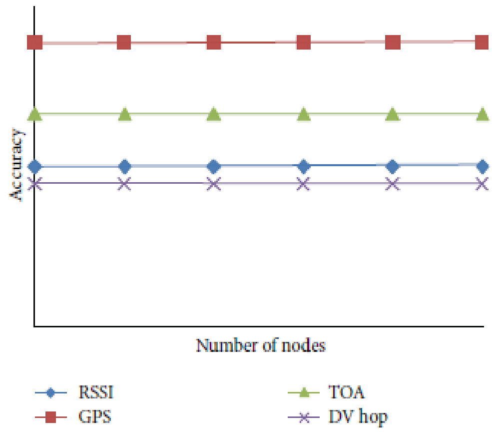

Figure 0:3 Accuracy of different localization techniques

3.9 Energy efficiency of different localization techniques

A comparison among different localization mechanisms in terms of energy efficiency and the increase of the number of nodes, the GPS-based scheme is high energy consumption which means less efficient as compared to RSSI-based technique [7], Figure 0:4.

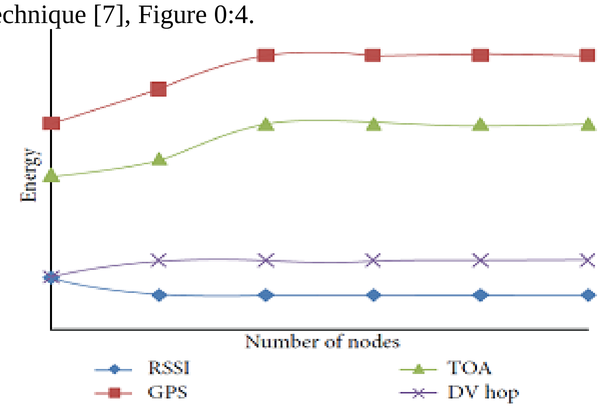

Figure 0:4 Energy efficiency of different localization technique

6.6 Different localization techniques

Applications for The largest cost and hardware size are those equipped with GPS and use the TOA and AOA techniques, as compared to GPS-free and RSSI and DV-hop which bring low cost and small hardware size with better energy efficiency and medium accuracy, Table 0-2.

Table 0-2 Comparison of different localization techniques

Technique	Cost	Accuracy	Energy efficient	Hardware size
GPS	high	high	less	large
GPS-free	low	medium	medium	small
centralized	depends	high	less	depends
decentralized	depends	low	high	depends
RSSI	low	medium	high	small
TOA	high	medium	less	large
TDOA	low	high	high	Simple/ large
AOA	high	low	medium	large
DV hop	low	medium	high	small
APIT	medium	medium	high	medium

6.7 Performance of localization schemes and limitations

Table 0-3 shows that each localization technique serves a different purpose, [16] suggested that the number of anchor nodes will reduce the localization error i.e. making the network dense for example in a closed environment with more obstructions.

Table 0-3: Localization techniques in terms of limitations and accuracy

Localization Techniques	Accuracy	Drawback
GPS	2m to 15m	indoor localization is not possible
proximity based	1m to 30m	depends on the range of the signal
angle based	1m to 8m	require a special antenna
range based	4m to 10m	require special hardware and time synchronization

6.8 Range-based and rage free

In

Table 0-4 the range-based algorithm (RSS), out per forms the Range-free algorithm (DV-Hops).

While

Table 0-5 shows range-based (Centroid) algorithm, has the worst accuracy performance. Whereas in terms of accuracy Table 0-6 shows that RSS is more accurate than DV-Hops and Centroid protocols by 55% and 85% respectively. While the worst case, RSS is more accurate from both DV-hop and Centroid protocols by 26% and 58% respectively [17].

Table 0-4: RSS localization system

Node ID	Exact Coordination X	Exact Coordination Y	Estimated Coordination X	Estimated Coordination Y	Error
1	12.9	4.2	14	3	1.6278821
2	20.05	11	21	9	2.4423349
3	29.58	15	29	14	1.0623088
4	33.9	4.1	35	4	1.1088733
5	46.48	5.8	45	5	1.6776472
6	40.07	10	41	9	1.3951702
7	28.45	3.6	27	4	1.5041609
8	18.83	1.6	19	2	0.4346263
9	13.72	12	15	11	1.5880806
10	30.5	13	29	12	1.630828

Table 0-5: Centroid localization system

Node ID	Exact Coordination X	Exact Coordination Y	Estimated Coordination X	Estimated Coordination Y	Error
1	14.76	55	19	55	4.24
2	26.65	60.37	23	61	3.7039708
3	40.44	57.74	39	55	3.0953514
4	49.92	63.83	49	61	2.9757856
5	64.81	55.64	59	55	5.8451433
6	21.18	59.85	19	55	5.3174148
7	25.49	65.64	29	61	5.8180495
8	38.65	60.37	39	55	5.3813939
9	51.18	58.48	49	61	3.3320864
10	60.65	60.22	59	55	5.4745685

Table 0-6: DV-Hop localization system

Node ID	Exact Coordination X	Exact Coordination Y	Estimated Coordination X	Estimated Coordination Y	Error
1	13.24	41.21	14	38	3.3016616
2	16.25	35.85	14	38	3.1120733
3	29.97	52.57	29	55	2.616448
4	29.4	52.66	29	55	2.3739419
5	45.47	40.99	47	39	2.5101793
6	46.82	39.95	47	39	0.9669023
7	47.47	40.78	47	39	1.8410052
8	10.83	38.83	14	38	3.2768583
9	12.78	39.5	14	38	1.9334942
10	45.2	42.1	47	39	3.5846897

6.9 Range-based and range-free localization algorithms

Below, Figure 0: 5 [24] states that in general error decrease as the range of radio increase for range-free localization algorithms and the Amorphous algorithm obtain the best result. [25] suggested an improved DV-hop algorithm; the overall accuracy is improved with the new algorithm as shown in Figure 0:6.

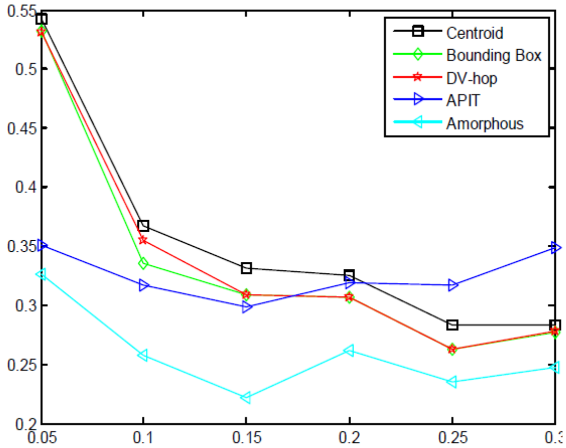

Figure 0: 5 Localization error with the change of anchor radio for Amorphous, APIT, DV-hop, Bounding Box, and Centroid

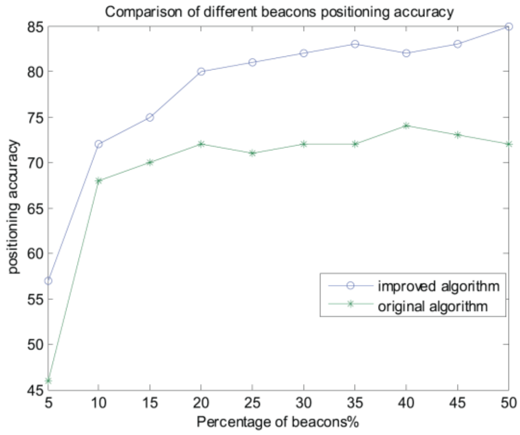

Figure 0:6 the positioning accuracy's picture about a different number of beacon nodes.

In Table 6-7 the range-based localization is high cost and precision more than range-free techniques and consumes more hardware.

Table 0-7: Comparison between range-free and range-based and localization techniques

parameter	range-based techniques	range-free techniques
cost	high	low
Power utilization	high	low
precision [26]	85-90%	70-75%
implementation	Complex	Easy
Hardware reliance	Yes	No

The cost, accuracy of individual algorithm techniques for both range-based and range-free algorithms are shown in

Table 0-8.

Table 0-8: General comparisons among range-free and range-based and localization algorithms

S. No.	Techniques	Cost	Accuracy	type
1	RSSI	Less	Less	range-based
2	Cola	Average	Average	range-based
3	ABC	Less	Less	range-based
4	MABT	Less	More	range-based
5	ERBL	More	More	range-based
6	LOTUS	Average	More	range-based
1	APIT	Low	High	range-free
2	SERLOC	High	Medium	range-free
3	Centroid	Low	Medium	range-free
4	DV Hop	Medium	High	range-free
5	Gradient	Low	Low	range-free
6	Spotlight	Low	Medium	range-free

6.10 A comparison between centralized and distributed localization

A preferable low cost with high precision in distributed techniques according to table 6-9, [26].

Table 0-9: Comparison of distributed and centralized localization

Parameter	Centralized techniques	Distributed techniques
Cost	High	Low
Power utilization	High	Low
Hardware's reliance	No	Yes
Precision [21]	70–75%	75–90%
Implementation	Complex	Easy

6.11 Comparison between common localization technologies

Table 0-10: Common technologies employed for localization

technologies or system employed for localization	common principles used for localization	range	environment suitability	power consumption	latency	precision	cost
RFID	RSSI, ToA	0.01-30 m	Room, indoors	Very low	low	Good (meters)	cheap
GPS	ToA	thousands of kilometers	urban and Rural	very good	very high	Good outdoors. Poor indoors	Costly infrastructure. Moderates receivers
Wi-Fi	RSSI fingerprinting, RSSI theoretical, Proximity, propagation model, TDoA, ToA.	1-200m	Urban, indoors.	high	low	Good (meters)	moderate
Bluetooth	RSSI fingerprinting, RSSI propagation	1-20m	Indoors, Room.	low	Medium	Good (meter)	High cost when increase in scale
Zigbee	RSSI fingerprinting, RSSI	1-50m	Urban, indoors.	very low	very	Good (meters)	cheap

	propagation				low		

The table shows that GPS has high cost with very high latency and distance up to several thousands of kilometers for outdoor use only, while other technologies with cheaper cost and range from 20-200m [39].

Protocols

1- Beacon protocol.
   a) Localization process initiated by anchor nodes.
2- Continuous ranging protocol.
   a) The blind node starts the localization process.
   b) The drawback is that blind node sends range message even if localization signal still not arrive.
3- Beacon protocol (optimized).
   a) The same as the beacon protocol.
   b) When unlocalized node overhears three range messages, the localization process will start without waiting for a neighbor node. When the blind node becomes aware of its location, it can localize other neighboring blind nodes [7].

Applications

Many applications that are using wireless sensor networks show a great deal while making these nodes position aware through localization schemes.

1. Cyber-physical systems.
2. Military [39].
3. Home and office automation [38], [18].
4. Weather forecasting [18].
5. Environmental monitoring [70].
   a) Forest fire detection [19].
   b) Flood detection [14].
   c) Structural integrity monitoring [19].
   d) Glacsweb.
   e) Monitoring volcanic eruptions (MVE)-WSN [19].
6. Health care [39].
   a) Night shift assistant.
   b) Backup shift assistant.
   c) Acute patient monitoring.
   d) Continuous care.
7. Mood-based services.
8. Positioning and animals tracking.
   a) Real-time relative positioning system.
9. Entertainment.
   a) Lea game show.
   b) At the nightclub.
   c) Virtual mood.
10. Logistics.
   a) Target tracking.
   b) Warehouse tracking.
   c) Management at the department store.
   d) Smart storage.
11. Transportation.
12. Home and office [18].
   a) Smart home.
   b) Smart office.
13. Industrial applications.
   a) Shopping at the store.
   b) Smart shopping list.
   c) Smart factory [19].

Simulators

In this survey, we mention wireless sensor network simulators that classified as free-license and used for educational purposes. The rest of the simulators with additional further details including commercial ones mentioned in [20] such as MATLAB.

Table 0-1: Wireless sensor networks simulators.

Simulator	Developed by	Programming language	**Advantages**	**Disadvantages**	**GUI**
ATEMU	University of Maryland	nesC, TinyOS	Emulation on a very low hardware level of sensor node. Xatdb, debug frontend, is a good educational tool.	Original version supports only MICA2 node. Poor scalability. Slow speed of simulation. Project seems to be abandoned.	average
Avrora	University of California, Los Angeles	Java	Very special application area, particularly for programs written for AVR microcontroller. Full support for MICA2 and MICAZ. Good scalability, up to 10 000 nodes.	It fails to model clock drift. No mobility support. Lack of visualization tool. 50% slower than TOSSIM.	poor
Castalia	National ICT Australia	C++	Good implementation of physical process models, sensors.	Not designed only for WSN.	excellent
COOJA	Swedish Institute of Computer Science	Java	Focus on both simulated software and hardware.	Extensive and time-dependent simulations are difficult. Supports a limited number of simultaneous types of nodes.	good
EmStar	University of California, Los Angeles	Linux	Use of component-based model provides good scalability.	Code execution only for some node types. No support for parallel simulation. Not efficient and fast as some other simulators. Project seems to be abandoned.	good
Ethernal	Wireshark	C/C++	Supports hundred of protocols.	Not a classical network simulator.	good
JiST/ SWANS	Cornell University	java, script Jython	Very efficient, good performance. Good scalability.	Lack of protocol models. Very poor GUI (log event only).	basic
JProwler	Vanderbilt University	Java	WSN simulator based on a probability. Very precise radio model.	Supports only one MAC protocol. Poor GUI.	basic
J-SIM	University of	java, script	Support for modeling energy	Low efficiency and speed of simulation. Only	average

	Illinois at Urbana-Champaign	jacl	consumption. Mobile WSN support. Component-based architecture.	one MAC protocol supported. Project seems to be abandoned.	
NS2	UC Berkeley	C++, script OTcl	Large community of users. Large number of available protocols.	Complex scripting. Support for only two WSN MAC protocols.	Good
NS3	UC Berkeley	C++, script Python	Better scalability comparing to NS2. Easier integration of external Software. Better WSN support.	Lack of some protocols available in NS2. Popularity still behind NS2.	Good
SENS	University of Illinois at Urbana-Champaign	C++, nesC	User can build application-specific environment. Environment is defined as a grid of tiles.	MAC protocol is not simulated precise enough. Only sensor support is for sound. Project seems to be abandoned.	average
SENSE	Rensselaer Polytechnic Institute NY	C++	Good tradeoff between modeling and efficiency. Fast, saves memory, easy to expand and reusable.	Not precise enough for evaluation of WSN. Lack of models. No visualization tool. Project seems to be abandoned.	average, with G-SENSE
Shawn	Institute for Telematics, University of Lubeck, Germany	C++	Easy to implement distributed protocols. It can simulate vast sensor networks.	No special WSN protocols, as algorithmic approach concentrates on lower layers.	average
TOSSIM	UC Berkeley	nesC, TinyOS	Precise TinyOS simulation. Capable	MICAZ is the only supported	good, with TinyViz
Visual Sense Ptolemy II	UC Berkeley	Java	Precise and expandable radio model. Precise sound models.	No support for protocols above wireless medium. No support for other sensor and physical phenomena except for sound.	good

Table 0-2: Simulators domains

Simulator	Flexibility	Scalability	Protocol base	Presentation of results	Energy consumption model	Radio signal propagation model
NS2	high	medium	large	good	yes	good
NS3	high	high	medium	good	yes	good
Ethereal/ Wireshark	medium	-	large	good	no	-
Castalia	high	medium	medium	excellent	yes	good
J-SIM	medium	low	medium	average	yes	average
JiST/SWANS	medium	very high	medium	basic	no	good
VisualSense/ Ptolemy II	medium	medium	small	good	yes	good
TOSSIM	medium	medium	small	good	yes, with Power TOSSIM	basic
EmStar	medium	low	medium	good	yes	average
ATEMU	medium	low	small	average	no	basic
SENSE	medium	medium	medium	average	yes	average
SENS	medium	medium	small	average	yes	good
JProwler	medium	medium	small	basic	no	basic
Avrora	high	medium	small	basic	yes	average
COOJA	high	medium	small	good	yes	good
Shawn	medium	high	small	average	yes	average

9. Conclusion

The structure of localization of wireless sensor networks differs from one application to another, and some of these techniques are suitable for indoor or outdoor use or both. The main objective of the sensor nodes is to locate the information received. The design of the nodes selected varies according to the environment in which they are used, such as localization indoor or outdoor. Many wireless sensor network applications prefer range-free methods over range-based methods due to the drawbacks of range-based localization schemes [26]. The use of GPS may face difficulties due to lack of energy sources or increased cost. There are a lot of factors that researchers should take in designing wireless sensor networks that will reduce cost and increase efficiency. Localization supports the pervasive computing applications which allow location data to be accessed and used by any application, for example accessing GPS from a mobile phone [28]. This paper aims to assist in the decision of choosing the best localization technique that fit the requirement. The density of the nodes, the type of device used and the environment are important factors in the design of the localization algorithms Localization still has a lot of space for new researchers, also the choice of simulation software depends on the case study used for research, most common parameters to select simulation environment are cost, programming language, and parameters that are possible to simulate such as energy consumption and radio signal propagation.

References

[1] Khan, Shafiullah, Al-Sakib Khan Pathan, and Nabil Ali Alrajeh, eds. *Wireless sensor networks: Current status and future trends*. CRC press, 2012.
[2] Du, Jinze. *Indoor localization techniques for wireless sensor networks*. Diss. université de Nantes, 2018.

[3] _Korial, Ayad Esho, and Mohammed Najm Abdullah. "Indoor Navigation for Visually Impaired/Blind People Using Smart Cane and Mobile Phone: Experimental Work." *Journal of Information Engineering and Applications* 6 (2016): 31-40.
[4] _Korial, Ayad E., and Mohammed N. Abdullah. "Novel method using beacon and smart phone for visually impaired/blind people." *Int. J. Comput. Appl* 1 (2016): 33-39.
[5] Nazir, U., et al. "Classification of localization algorithms for wireless sensor network: A survey." *2012 International Conference on Open Source Systems and Technologies*. IEEE, 2012.
[6] Bulusu, Nirupama, John Heidemann, and Deborah Estrin. "GPS-less low-cost outdoor localization for very small devices." *IEEE personal communications* 7.5 (2000): 28-34.
[7] Alrajeh, Nabil Ali, Maryam Bashir, and Bilal Shams. "Localization techniques in wireless sensor networks." *International Journal of Distributed Sensor Networks* 9.6 (2013): 304628.
[8] Mekelleche, Fatiha, and Hafid Haffaf. "Classification and Comparison of Range-Based Localization Techniques in Wireless Sensor Networks." *Journal of Communications* 12.4 (2017).
[9] Niewiadomska-Szynkiewicz, Ewa. "Localization in wireless sensor networks: Classification and evaluation of techniques." *International Journal of Applied Mathematics and Computer Science* 22.2 (2012): 281-297.
[10] Nazir, U., et al. "Classification of localization algorithms for wireless sensor network: A survey." *2012 International Conference on Open Source Systems and Technologies*. IEEE, 2012.
[11] Boukerche, Azzedine, ed. *Algorithms and protocols for wireless sensor networks*. Vol. 62. John Wiley & Sons, 2008.
[12] Zhang, Xue. *Localization in wireless sensor networks*. Arizona State University, 2016.
[13] Singh, Santar Pal, and S. C. Sharma. "Range free localization techniques in wireless sensor networks: A review." *Procedia Computer Science* 57 (2015): 7-16.
[14] Akyildiz, Ian F., and Mehmet Can Vuran. *Wireless sensor networks*. Vol. 4. John Wiley & Sons, 2010.
[15] Nikoletseas, Sotiris, and José DP Rolim. *Theoretical aspects of distributed computing in sensor networks*. Berlin: Springer, 2011.
[16] Kuriakose, Jeril, V. Amruth, and N. Swathy Nandhini. "A survey on localization of wireless sensor nodes." *Information Communication and Embedded Systems (ICICES), 2014 International Conference on*. IEEE, 2014.
[17] Shahra, Essa Qasem, Tarek Rahil Sheltami, and Elhadi M. Shakshuki. "A comparative study of range-free and range-based localization protocols for wireless sensor network: Using cooja simulator." *International Journal of Distributed Systems and Technologies (IJDST)* 8.1 (2017): 1-16.
[18] Chowdhury, Tashnim JS, et al. "Advances on localization techniques for wireless sensor networks: A survey." *Computer Networks* 110 (2016): 284-305.
[19] Roberto Verdone, Davide Dardari, Gianluca Mazzini, Andrea Conti,
[20] Applications of WSANs,Editor(s): Roberto Verdone, Davide Dardari, Gianluca Mazzini, Andrea Conti, Wireless Sensor and Actuator Networks, Academic Press, 2008, Pages 13-43, ISBN 9780123725394.
[21] Živković, M. I. O. D. R. A. G., et al. "A survey and classification of wireless sensor networks simulators based on the domain of use." *Adhoc & Sensor Wireless Networks* 20 (2014).
[22] Gupta, Sandeep KS, et al. "An overview of pervasive computing." *IEEE Personal Communications* 8.4 (2001): 8-9.
[23] Zhao, Erdun, et al. "Performance Evaluation of Localization Algorithms with Measurement Errors in WSNs." *Wireless Communications, Networking and Mobile Computing (WiCOM), 2011 7th International Conference on*. IEEE, 2011.
[24] Singh, Santar Pal, and S. C. Sharma. "Range free localization techniques in wireless sensor networks: A review." *Procedia Computer Science* 57 (2015): 7-16.
[25] Li, Shelei, Xueyong Ding, and Tingting Yang. "Analysis of five typical localization algorithms for wireless sensor networks." *Wireless Sensor Network* 7.04 (2015): 27.
[26] Liu, Dongxiao, Yujun Kuang, and Wei Wei. "Research and improvement of DVHOP localization algorithm in wireless sensor networks." *Computational Problem-Solving (ICCP), 2010 International Conference on*. IEEE, 2010.
[27] Hamdani, Maryum, et al. "A Comparison of Modern Localization Techniques in Wireless Sensor Networks (WSNs)." *Proceedings of the Future Technologies Conference*. Springer, Cham, 2018.
[28] Zhang, Yan, Laurence T. Yang, and Jiming Chen, eds. *RFID and sensor networks: architectures, protocols, security, and integrations*. CRC Press, 2009.
[29] Chakroun, Omar, Martin Hild, and Bessam Abdulrazak. "*Indoor and Outdoor Localization Framework for Pervasive Environments*".
[30] Mesmoudi, Asma, Mohammed Feham, and Nabila Labraoui. "*Wireless sensor networks localization algorithms: a comprehensive survey.*" arXiv preprint arXiv:1312.4082 (2013).
[31] Riddle, Alfy. "RFID for All [review of" RFID Technology and Applications" by SB Miles, SE Sarma, and JR Williams; 2008]." *IEEE Microwave Magazine* 9.6 (2008): 176-176.
[32] Karl, Holger, and Andreas Willig. *Protocols and architectures for wireless sensor networks*. John Wiley & Sons, 2007.
[33] Paul, Anup Kumar, and Takuro Sato. "Localization in Wireless Sensor Networks: A Survey on Algorithms, Measurement Techniques, Applications and Challenges." *Journal of Sensor and Actuator Networks* 6.4 (2017): 24.
[34] Mao, Guoqiang, ed. *Localization Algorithms and Strategies for Wireless Sensor Networks: Monitoring and Surveillance Techniques for Target Tracking: Monitoring and Surveillance Techniques for Target Tracking*. IGI Global, 2009.
[35] Han, Guangjie, et al. "A Survey on Mobile Anchor Node Assisted Localization in Wireless Sensor Networks." *IEEE Communications Surveys and Tutorials* 18.3 (2016): 2220-2243.

[36] Behnke, Ralf, Jakob Salzmann, and Dirk Timmermann. "Improvements on scalable distributed least squares localization for large wireless sensor networks." *Wireless Pervasive Computing (ISWPC), 2010 5th IEEE International Symposium on*. IEEE, 2010.
[37] Diamond, Scott M., and Marion G. Ceruti. "Application of wireless sensor network to military information integration." *Industrial Informatics, 2007 5th IEEE International Conference on*. Vol. 1. IEEE, 2007.
[38] Zekavat, Reza, and R. Michael Buehrer. *Handbook of position location: Theory, practice and advances*. Vol. 27. John Wiley & Sons, 2011.
[39] Pereira, Vasco Nuno Simões. *Performance Measurement in Wireless Sensor Networks*. Diss. 2016.
[40] Ahson, Syed A., and Mohammad Ilyas, eds. *Location-based services handbook: Applications, technologies, and security*. CRC Press, 2010.
[41] Keshtgary, Manijeh, Masood Fasihy, and Zahra Ronaghi. "Performance evaluation of hop-based range-free localization methods in wireless sensor networks." *ISRN Communications and Networking* 2011 (2011).