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A big picture on localization algorithms considering sensor logic location

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***Abstract*—Wireless sensor networks (WSNs) have been applied in areas such as military surveillance, environmental monitoring, habitat and structural monitoring, domotics, battlefield surveillance and robotics. The aim of this survey is to present the state-of-the-art in localization algorithms which consider the combination of different factors such as localization schemes, propagation models, communication protocols, traffic patterns analysis and sensor logic location. The latter represents the inherent characteristic of the object to which the sensor is attached to. We believe that the precision of the localization algorithms can be improved when these factors are considered as whole rather than isolated effects. A classification and the main solutions for each factor are presented. The advantages, performance issues and the relation of the solutions with the other factors are discussed. The article concludes with opened research questions and possible further research directions.**

***Keywords*— WSN, localization schemes, communication protocols, traffic pattern analysis, sensor logic location.**

I. INTRODUCTION

Wireless sensor networks (WSNs) have been integrated into domains such as military surveillance, environmental monitoring, habitat and structural monitoring, domotics, battlefield surveillance and robotics. WSNs in habitat monitoring can detect fire, in agriculture the nodes can sense humidity and in disaster events (earthquake) can locate a person. Node localization is then a key factor for some applications. There are numerous localization algorithms with different accuracy and approach. Despite the relative high accuracy of some algorithms this is still an opened research question given all the different constraints of some applications such as power consumption, storage capacity, cost and scalability, etc. New algorithms are being developed and even new paradigms of how they can be implemented such as localization protocol composition [1] [2]. It has been proved in [1] and [2] that by employing different algorithms in a structured way (node localization architecture) higher accuracy can be achieved than by the individual algorithms. In this sense we believe that traffic pattern characterization (TPC) and sensor logic location (SLL) can be employed to improve the location estimation of any individual algorithm. The use of TPC and SLL is regardless of WSN properties such as node mobility, beacon node presence, topology, density of nodes, with or without beacons, etc. This includes the algorithm approach such as range-based or free-range.

Traffic analysis is a common and well understood area in communication networks such as the Internet. However, this may not be the case for WSN. The information provided by such analysis has been applied in different ways. In [3] it has been used to infer the network topology considering elapsed time, destination address, active message type, length, source and originating fields. In [20] [21] [22] countermeasure attack techniques based on traffic analysis are presented. The goal is to make traffic patterns as random as possible while minimizing cost to prevent attacks on base stations. Some other WSN metrics have been characterized such as energy consumption [4] and localization error [5].

We define sensor logic location as the use of inherent attributes of the objects (vehicle, robot, computer, table, printer, etc.) which can carry or hold a sensor considering the environment properties (physical restrictions, obstacles, communication protocol, etc.) in order to validate the possible sensor positions. The localization schemes (LS) accuracy is affected by environmental factors such as humidity, reflection, scattering, attenuation, etc. This even includes the water; the human body is made up of water and wall obstruction as stated in [7].

To consider these factors the localization algorithms may employ their mathematical models to achieve a better estimation. Some of these models are already include in simulators. This is the case of AVRORAZ [6] which employs an indoor and outdoor propagation model [24].

There are many different kinds of wireless technologies such as wireless-fidelity (WIFI), ultra-wideband (UWB), bluetooth, cellular network and zigbee. They define how devices of the same technology communicate with each other and in some cases from different technology. These definitions affect how packets are transmitted among the nodes and issues such as power consumption, network overhead and throughput, security, etc. Some definitions are discussed in section IV.

A possible solution to the localization problem is the use of GPS. However, this may not be case for indoors environments and because of issues costs. Some LS which overcome the use of GPS are [8] [9] [11] [12].

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This survey discusses five key factors that may be considered to improve node localization: (1) localization algorithm or schemes, (2) propagation models, (3) communication protocols, (4) traffic patterns and (5) sensors logic location. This paper is organized as follows. In section 2 it presents classification and comparison of different localization schemes. In section 3 indoor and outdoor propagation models are reviewed. In section 4 packet transmissions in WSN is discussed. In section 5 traffic pattern analysis in WSN is reviewed. Finally, section 6 concludes the survey and presents opened research directions bearing in mind sensor logic location.

II. LOCALIZATION SCHEMES (LS)

There are three import issues related with localization: accuracy, energy efficiency and security. This section is focused in the accuracy.

The accuracy is the degree of closeness of a real position of the node. In the area of LS, the beacons are known position nodes. These are also referred to as seed, anchor or locator nodes. For regular node their position is unknown. Both types can be fixed or mobile. There are different methods to estimate the position of a node. These are classification as range-based which uses distance (vicinity) or angles for the localization and free-range which is based only the contents of the received messages.

Some examples for range-based are AoA, RSSI, ToA, and TDoA and free-based are Amorphous, APIT, Centroid, Bounding box, DV-Hop, MDS, SeRLoc and ROCRSSI [8] [9] [10] [11] [12] although in [1] [2] use a composability of some localization methods.

The Active Badge system [15] provides an estimate localization of individuals within a building through the location of their Active Badge. The badge has a size of 55x55x7mm, weighs 40g and sends a unique infra-red signal every 10 or 15 seconds which has a range of 6m, moreover the signal cannot travel through a wall, unlike radio signal. The beacons were positioned in the offices, common areas and major corridors. The Active Badge turns the badge off to conserve energy when dark. On the other hand, the system updates the user position every 10 or 15 seconds, it may be disadvantage in some case. There are some bad positions for the badge such inside of clothing or over the belt, because when the user is seated at a desk, it hinders the transmission.

RADAR [7] is a radio-frequency based system for locating and tracking users inside buildings. RADAR uses the signal strength only from three base stations into the building. RADAR was developed in a fully observable environment and it uses empirical measurements to infer user location by triangulation. The system considers the Wall Attenuation Factor (WAF) based on Floor Attenuation Factor Propagation model. But requires extensive infrastructure effort and it is not quick to implement in other different indoor place, since the generation of the signal database needs considerable time. In general the radio-frequency systems suffer problems such as multi-path fading, background interference, and irregular signal propagation characteristics.

SpotON [13], it is also radio-frequency based. It is a tagging technology for three dimensional location sensing based on radio signal strength. The base stations are connected only by RS-232 serial connection, therefore the number of physical serial ports on the server may be limited. To solve this constrain, SpotON uses a device called hydra microwebserver which can be used to extend its base stations through Ethernet. This system uses an empirical formula to estimate sensor position.

PinPtr [14] is a Sniper-detecting system which uses acoustic measurements. When a projectile is fired it produces a spherical wave and each certain distance there is a point which generates a cone-shaped wave, then the system can uses formed angles to estimate the sound source, therefore the shooter position. The main limiting signaled by them is a line-of-sight requirement. The system has not been proved for more than two shooters shooting at the same time or random time. PinPtr could not work well if there are shooters one against another shooting at the same time.

In [1] [2] a framework is proposed which uses the combination of four different localization schemes. Their architecture has two phases in the first one work Spotlight and GPS, in the second phase work centroid and DV-Hop. The architecture component called Localization Manager (LManager) plays the most important roll, it contains a hierarchy of localization schemes to be executed in the network, is responsible for neighboring nodes executing the same localization protocol, aggregates results from multiple localization protocols simultaneously executed, is responsible for dynamically loading localization schemes, it can change a node to beacon and LManager has the ability to stop the execution of a localization protocol or inquire about the status of execution, among others. With this architecture they propose to reduce by 50% the error location. 10% of the entire nodes have GPS, but GPS is expensive. All the different localization schemes that they use have different intrinsic constraints.

In [9] the localization algorithm uses the Sequential Monte Carlo (SMC) to estimate the distribution of the possible node localization from a set of samples with weight, the advantages of SMC is that it improves over time. In this algorithm each step is dived into two phases, the first one is called prediction; in this phase when a robot makes a movement, the uncertainty of its position increases and uses the previous position to predict the actual position; the second phase is named update, in this phase new measurements are added to filter and update data, which means observations of new landmark. This approach takes advantage of the mobility to improve the accuracy and reduces the numbers of seeds. The wave propagation irregularity is considered, they use degree of irregularity (DOI) which is defined as an indicator of ratio pattern irregularity. For example if DOI=0.3, then the radio range in each direction has a random value from 0.7r to 1,3r. Besides, the nodes and beacons can move randomly and independently.

APIT [12] is an area-based approach. In this scheme the density of beacons is an important factor to consider, because the seeds form triangles, where each vertex is a seed. These "beacon triangles" are formed by three random beacons. After, the node analysis whether it is inside one o more "beacon triangles". Later, the node calculates the intersection of the "beacon triangles" and chooses the centroid of this area.

A synopsis of the localization schemes is presented in the Table 1.

TABLE I

Methods	Accuracy	Nodes	Over-head	Architec-ture	Environ-ment	Range base/range free
AoA	Good	N/S	N/S	Distributed	Outdoor	range base
RSSI	Fair	N/S	N/S	centralized	Indoor	range base
ToA	Good	N/S	N/S	Distributed	Outdoor	range base
TDoA	Good	N/S	N/S	Distributed	Outdoor	range base
Amorphous	Good	>16	Large	Distributed	Outdoor	range free
APIT	Good	>16	Small	Distributed	Outdoor	range free
Centroid	Fair	>10	Small	Distributed	Both	range free
Bounding Box	Good	>16	Small	Distributed	Both	range free
DV-Hop	Good	>16	Large	Distributed	Outdoor	range free
MDS	Good	N/S	Large	Centralized	Outdoor	Both

N/S =Not Specified.

(*)NOTE: The algorithms were performed in different simulator (NS-2, TOSSIM, AVRORA, etc) under different situations (density of nodes, topology) therefore some result may be different.

III. PROPAGATION MODEL (PM)

How the waves propagate and are affected for different factors such as frequency, free spaces loss, attenuation, antenna gain, and width of the beam, multi-paths, reflection, diffraction, scattering and son on are important aspect to considerate for designing transmitters, receivers, embedded system, simulators and others.

Some ALs have taken into count propagation models with an attempt to be more accuracy. How models are represented by mathematical formalisms it allows add more variable and we can build more complex models such [7].

We show propagation wave, major factors to affect the wave and how can be represented mainly in the next subsections.

A. Free space propagation.

The Friis transmission formula is show in (1):

$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi d)^2} \quad (1)$$

Where *Pr* is the power of the receiver signal, *Pt* is the power of transmitter signal, *Pr* is the receiver antenna gain, *Pt* is the transmitter antenna gain, *d* is the distance between the receiver and transmitter, *λ* is the wavelength and *π* is a constant. However it assumes the next ideal conditions: A) the antennas are aligned and polarized, B) the bandwidth is enough and the wavelength can be assumed. C) There are not obstacles between the antennas and without multi-path, D) The receiver antenna power and transmitter antenna power are always available and without loss of power. If we want to know the propagation loss (Lp) which is the attenuation suffered by the signal, we can consider (2), (3) and (4).

$$L_p = \log\left[\frac{4\pi d}{\lambda}\right]^2 \quad (2)$$

Where *π, d* and *λ* have the same meaning that Friis transmission formula. Propagation loss in free space in (3):

$$L_p = 32.44 + 20\log(r \cdot f) \quad (3)$$

Lp in dB, where *r* is in Km and *f* is en MHz

Path loss exponent in dB is shown in (4):

$$L_p = 10n\log(d) + C \quad (4)$$

Where *n* is the path exponent, when *n* is equal to 2, it represents propagation in free space, in some indoor environments the value is from 4 to 6 such as building and stadiums. *C* is a constant; *d* is the distance between the receiver and the transmitter.

B. Propagation mechanics

1) Reflection: It is the change of direction of a wave in a surface. Some kinds of reflections:

a) Diffuse reflection: When the wave hits on rough surface, therefore the shape of the reflection depends on the configuration of the surface.

b) Retroreflection: Form of the surface can return the wave in the same direction from which it arrived.

c) Complex conjugate reflection: The wavefronts are reversed.

2) Refraction: It is the change of direction of a wave through an object or a medium. Some Kinds of refractions:

a) Isotropic: single refraction such gases, liquids, glasses and diamond.

b) Uniaxial negative: Double refraction such calcite, tourmaline and sodium nitrate.

c) Uniaxial positive: Double refraction such calcite, tourmaline and sodium nitrate.

d) Biaxial: Triple refraction such mica, perovskite and topaz.

3) Scattering: The wave is scattering in many directions when impacts an object. Some types of scattering:

a) Brillouin scattering: The wave interacts with time dependent density variations and changes its path and frequency.

b) Rayleigh scattering: Rayleigh scattering: more usual in gases; the blue color of the sky is provoked by this kind of scattering.

4) Diffraction: The wave propagates into shadowed region; example the hologram on a credit card or rainbow of a CD when we look at.

C. Fading and Path loss

1) Small scale fading: It is also known as multipath, which means that the signal emitted by the sender will arrive to two or more paths to the receiver.

2) Large scale fading: It is also known as shadowing. It is characterized by propagation loss.

D. Propagation models classification

1) Empirical models: They are based mainly on data measurements (statistical properties).

2) Deterministic models: They Require high computational effort and the accuracy is better that empirical models.

3) Semi-deterministic models: They are based on empirical models and deterministic aspects.

There are different propagation models depending on environmental conditions. Some outdoor models are okumura model, COST hata model, young model, point to point lee model, area to area lee model, hata models for urban areas, hata models for suburban areas, hata model for open areas, ITU terrain model, egli model and longley-rice model. Some indoor models are ITU model for indoor attenuation and long-distance path loss model.

E. Related work

RADAR [7] uses the Wall Attenuation Factor (WAF) model which was derived from Floor Attenuation Factor propagation model. It is described by (5):

$$P(d)[dBm] = P(d_o)[dBm] - 10n\left(\frac{d}{d_o}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases} \quad (5)$$

Where n is path loss, $P(d_o)$ is the signal power at some reference distance d_o, d is the distances between the transmitter and the receiver, C is the maximum number of obstructions (walls) up to which the attenuation factor makes a difference, nW is number of obstructions (walls) between link, WAF is the wall attenuation factor. The WAF model does not take into count for multipath propagation.

The developers of centroid method [8] in their idealized model make two assumption: 1) Perfect spherical radio propagation and 2) Identical transmission range, unlike APIT [12] which uses DOI=0.1 and DOI=0.2. Their result in indoor environments was from 4.6m to 22.3m and outdoor environment the result was 2m in an environment of 10x10m. The implementation of this algorithm is relatively easy and it is easily extendable to 3D.

In [6] is proposed the extension of the simulator AVRORA with an IEEE 802.15.4 compliant radio chip model, moreover the developers establish an indoor propagation model, which uses the combination of the Rayleigh distribution and log-normal distribution when there are obstacles in the transmission range, on the other hand, when there are not obstacles that means a good communication channel it is characterized by Ricean Fading. This can be expressed by (6):

$$F = A \cdot P_{RICE}(K) + (1 - A) \cdot P_{LN}(\sigma_s, \mu_s) P_{RAYLEIGH} \quad (6)$$

Where the factor k representing the ratio between direct-path power and diffuse power. A, σ_s and μ_s are defined by (7), (8) and (9):

$$A = (1 - \rho)^{0.21} \quad (7)$$

Where ρ (m^{-2}) is the number of people or obstacles, and 1 (m) represents the length of the ray.

$$\sigma_s = \log_7(551\rho + 1) + 0.5 \quad (8)$$

$$\mu_s = (31\rho)^{0.7} \quad (9)$$

AVRORAZ [6] supports Received Signal Strength Indicator (RSSI), Link Quality Indicator (LQI), activation and deactivation of the radio transceiver, Energy Detection (ED), Clear Channel Assessment (CCA) and channel frequency selection.

IV. Wireless communication protocol (WCP)

The WCP are a set of rules establish to allow the communication among devices with the same wireless technology, although there are some works to join different communication protocols like in [26], where merge two segments of Control Area Network (CAN) with one of WIFI, this is achieved by putting one package of CAN in the payload of WIFI according to the specifications of Society of Automotive Engineers (SAE).

The wireless technologies such as wireless-fidelity (WIFI), ultra-wideband (UWB), bluetooth, cellular network and zigbee use different standard, for example bluetooth uses IEEE 802.15.1 standard and zigbee uses IEEE 802.15.4 standard [25]. Besides how the WSN is formed (topology), how the package are disseminated and what kind of medium access control (MAC) is used, influence the energy consumption, delay, collisions, retransmissions among others. When a receiver receives more than one package at the same time a collision occurs, then the senders must to send the packages again, the retransmissions increase the energy consumption.

In a shared medium, devices need a multiple-access protocol to coordinate access to the link. MAC is divided into two broad branches which are contention free and contention based. The classification of MAC is showed in the Fig. 1 and Fig 2.

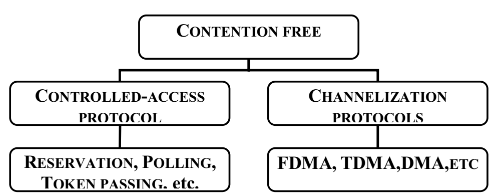

Figure 1. Contention free

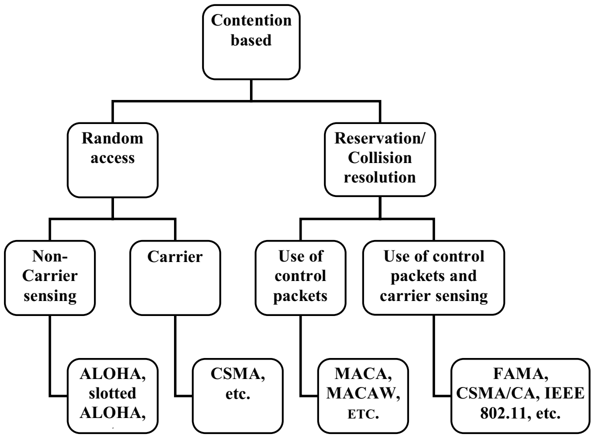

Figure 2. Contention based

In [24] propose a self-configurable system, it is a generic architecture which supports heterogeneous nodes, they assume a certain subset of the sensor to be immobile. The node routers are fix and form the backbone for communication, the routing architecture is hierarchical and groups of nodes can be formed and merge when needed. The Local Markov Loops (LML) performs a random walk on spanning trees of the graph. In this system improvements the energy consumption, computation and storage power, reduction of state and localized operations. In organizational phase, the hierarchical of the groups is formed; the routing table has a small maintenance cost.

In [17] Proposes traffic adaptive to improve energy consumption mainly, they identified the wasting sources as collision, control package overhead and idle listening and they show the effectiveness of their protocol comparing with 802.15.4. In 802.15.4 MAC the packages received are buffered in TX queue, if 80% or more of the queue are occupied, the node reports its queue status with Queue Status Indicator (QSI), however it is consider as data packages, therefore QSI has to await until all the previous 80% of the packages are dispatched. The QSI package is used to maximize the active period, this approach moves the QSI package to the first position in the TX queue, therefore they increase the active duty cycle in high traffic conditions and decrease the active duty cycle when the traffic is slow, this way the system saves energy.

The ways to deliver the data depend of the aim of the application, in some critical system the energy consumption is not primary factor such as [20] [21] [22] are focused on protecting the base station of an attack, through the introductions of random fake paths, random areas with high communication, random multi-hop path from sensor node to base station and false sink.

V. TRAFFIC PATTERNS CHARACTERIZATION (TPC)

Patterns recognition aims to classify data, if some computer system has categories of data and some data can be classified into one of these, therefore the system can executed certain or specific process according its specifications. Patterns recognition is a sub-topic of machine learning; however it has used in networks of computers.

There are many works about traffic patterns of LAN and Internet but, this may be not the case for WSN. The traffic patterns can help us to determine the topology of a WSN as in [16] they consider elapsed time, destination address, AM type, length, source and originating fields in the captured file to determine the two different topologies (direct connection and daisy-chained connection).

We suppose a WSN uses an excellent encryption system and it is impossible to get any information from the packages; however the traffic provoked can be analyze and find the base station. The packages are delivery in the base station at least of one hop, therefore the nodes near of the base station must retransmit the other packages, in this sense, the attacker can detect a bigger amount of traffic in certain area and discover the base station. To solve this problem there are techniques to deliver the information such as [20] [21] [22].

Some patterns that we can analyze in WSN are for example:

1. Type of packages delivered.
2. Behavior and transaction patterns of different kinds of packets.
3. Statistical estimation of self-similarity based on the package size and interarrival time between packages.
4. Statistical behavior of package size and interarrival time between packages.
5. PER, Jitter, attenuation, delay, RSSI and LQI.

In reference to second point, [16] shows the hypothesis for which wireless traffic is self-similarity and revises the consequences of this property.

In [17] studies the traffic patterns to achieve high energy efficiency and high performance at the same time.

In [18] has characterized the 802.11 traffic as analyzing MAC time, RSSI, signal quality, signal strength, noise and signal nose ratio and data rate and the same time captures collecting SNMP data and wired monitoring; introduces wireless monitoring as a traffic characterization technique. When it merges the data from the different sniffers it obtains a better view of traffic and an acceptable capturing performance.

In [19] shows the formulas to performance metrics as event reliability, node reliability, node efficiency, congestion degree, sink-received throughput, network fairness, deadline miss ratio, package loss ratio, energy loss, residual energy and network lifetime.

In [23] shows traffic models for medical WSN generated from two different kinds of data, which are electrocardiogram (ECG) and temperature body data. The variations of the data are so distinguish, in ECG data the changes are sudden and the temperature body data is slow. The models are based on existing public medical signal databases. The ECG model traffic is $Y_n = |aX_n|$ and body temperature traffic model is $Y_n = |aX_{n-1} + X_n|$, which we can generate the nth sample in the traffic profile, where X_n is a vector of independent zero mean Gaussian distributed random values and it is 11_{th} order AR model.

VI. CONCLUSION

To the best of our knowledge there is not a unique highly accurate localization scheme for all the possible application scenarios. The localization problem can be studied considering LS, PM, WCP, TP and SLL. When all of them are considered at the same time it opens an interesting research area. We have presented a broad overview, a classification and related work for each key factor. We certainly believe that considering the object's inherent characteristics into the localization of sensors can improve their accuracy. However, this be applicable to partially observable environments or fully observable environments. Logic position for objects can be defined such as tables, printers, chairs, persons where sensor are placed. Consider the next idea assuming a table cannot be over a table, can a table float? This would be unrealistic but must localization schemes don´t take this into account. This is a current research line taken by the authors. Result of these ideas will be published in the near future.

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