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Localization, Routing and Data Gathering in Wireless Sensor Networks (WSNs)

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Abstract: Wireless Sensor Networks (WSNs) are a common place nowadays. These networks consist of a huge number of small, low power and cheap commodities, capable of sensing, processing and communicating with each other to carry out the required task(s). WSNs have many emerging and attracting applications with wide deployment in both military and commercial sectors; however, it is not a fully mature field yet, so research is continue on numerous topics. Some open research issues of WSNs include localization, routing protocols, topology control, design of middleware architectures, development of new simulation and debugging tools, etc. In this paper, we are presenting a comprehensive survey on three main issues of WSNs, which include localization, routing and data gathering. Additionally, we have also highlighted a key problem in the research of localization in WSNs along with a theoretical model as its solution.

Keywords*:* Data Gathering Wireless Sensor Networks (WSNs)

1. INTRODUCTION

Wireless Sensor Networks (WSNs) comprise a large number of small, inexpensive and low power sensing devices (usually called sensor nodes), which are densely deployed to measure a given physical phenomenon. WSNs have many attractive and emerging applications including military (e.g. battle field management, monitoring of equipment), environmental control and monitoring (e.g. flood and

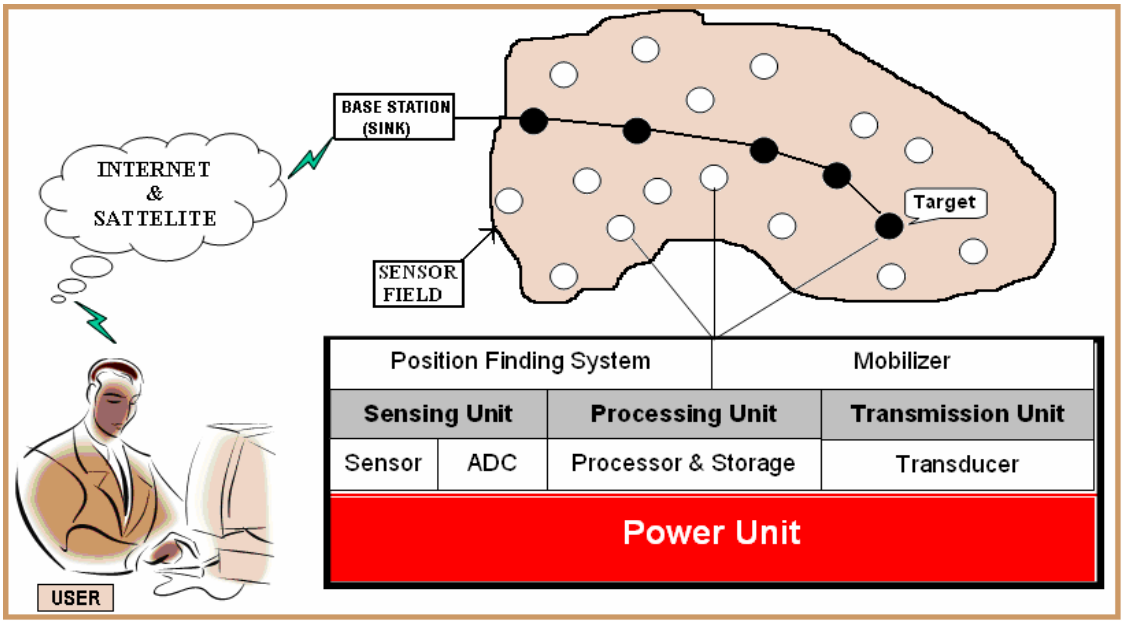


Fig-1: A simple scenario of wireless sensor network

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fire detection), health care, traffic control system, smart home/office environments, interactive games and toys, etc. Research in this field is on going in a variety of topics including localization, power aware topology control, routing, development of middleware architectures, security, simulation and debugging tools, etc. Figure 1 shows a simple scenario of WSNs. Sensors within a sensor field can be categorized as base station (sink) and ordinary nodes. Base station or sink serves the purpose of destination for sensor's data. Base station usually can be a PDA, laptop, desktop computer or any other computing device, which is more powerful than ordinary nodes in terms of power, computation and storage. An ordinary node performs two major tasks: first, sensing physical phenomenon, perform some computation (if necessary) and forward it. Second, it also works as a relay point (being an intermediate node) for other sensor nodes to route the data. A typical sensor may consist of 4 major parts **(as shown in Fig.1)** sensing unit, processing unit, transmission unit and power unit. Sensing unit facilitates to sense a physical phenomenon. Processing unit facilitates for computation and storage. Transmission unit contains a transducer to send and receive radio signals and power unit provides battery power for sensor node to operate.

The focus of this paper is to give the reader a compressive overview of sensor networks in general and localization in particular. In this paper we have highlighted the three main issues in sensor networks and then emphasize on localization and also presented a model as one of its solution.

The remaining part of this paper is organized as follows: section 2 is background, which presents the literature survey of WSNs and consequently identifies three key research areas in the field of WSNs, which include location detection techniques, routing protocols and query processing, section 3 further highlights the importance of localization in WSNs and presents the problem statement, in section 4 we have presented a model for localization of sensor nodes, section 5 is discussion and section 6 concludes the paper.

2. BACKGROUND

A. Localization

"The process of calculating or estimating spatial-coordinates of the node is referred to as Localization" (Jayashree, 2006).

In other words, localization means location or position estimation of sensor nodes within the sensor field. There is lot of literature on location discovery in WSNs. Before going into the detail, let us see why localization is important in WSNs. The reason is most of the applications in WSNs heavily rely on the location or position information of sensor nodes. Examples of such applications include forest fire detection, tracking and monitoring of doctors and patients inside a hospital, tracking of enemy forces in a battlefield and traffic control system etc. Another reason is, in traditional networks IP addresses are used to identify the computers within the network to carry out the communication & other network tasks. While the IP mechanism is not a viable solution for sensor networks due to the dense deployment of sensor nodes (Akkaya, 2003) Moreover, to achieve load balancing in topology control mechanisms location information is required. For example, in a dense deployment of sensor network, location information of nodes can be used to selectively shut down some nodes to save energy (Krishnamachari, 2005). Due to these and few other reasons researchers proposed many solutions for location detection issue of WSNs.

One of the first solutions to location detection is Global Positioning System (GPS). Benefits of GPS include location accuracy, reliability and global coverage. Since GPS approach requires that each node must have GPS receiver, thus it increases the hardware and also the cost of sensors. Second thing, GPS is not a reliable source of identity (location discovery) in indoor environments. Consequently, researchers proposed many alternative techniques and schemes to calculate the locations of sensor nodes, without the help of GPS. In general, location estimation algorithms can be categorized as Range-Based and Range-Free techniques (Yu, 2006 and He, 2003).

Range-Based techniques use absolute point-to-point distance or angle information between nodes to calculate the location of sensors. Well-known range-based techniques are Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA) and Received Signal Strength Indicator (RSSI) (Yu, 2006 and He, 2003).

ToA technology is used to obtain range information via signal propagation time. GPS uses ToA technique to calculate the position of an object with the help of satellites. TDoA uses both radio and sound signals to calculate the distance between nodes. It uses hardware mechanism, so it requires that each node must equip with a speaker and a microphone. In TDoA, the transmitter sends a radio message to all listening nodes. Concurrently, it also sends a sound signal (e.g. 4 KHz tone signal). When listening nodes

receive the radio signal, they note the current time, and start counting, simultaneously they also turn on their microphones. When these nodes detect sound signal, they again note the current time. Then they send back a radio message to sender (base station) including time difference of radio signal and sound signal. Then, distance between nodes can be calculated based on the time difference of radio and sound signal. ToA and TDoA are accurate under line-of-sight, which is difficult to meet in some environments. TDoA is also not suitable for noisy environments. Some algorithms exploit AoA approach. Usually radio or microphone arrays are used to gather AoA data, which allow a listening node to determine the direction of a transmitting node. Like TDoA and ToA it also requires bulkier hardware, thus it is expensive too. RSSI utilizes the radio power of sensor nodes. In this approach, listening node calculates its distance from transmitter, based on the strength of signal. RSSI is less expensive solution for localization problem, as it does not require additional hardware. The problem with RSSI is its less accuracy as compared to previous approaches due to the noise in radio signal (Yu, 2006 and He, 2003).

Range-free schemes, usually do not make use of point-to-point distance or angle information, but some other characteristics of radio signals, such as the contents of received or broadcast messages from neighboring sensors or anchor nodes (Yu, 2006 and He, 2003). Anchor nodes are special nodes which know their position a priori through GPS or programmatically. DV-Hop Count Localization (Niculescu, 2001) is an example of range-free approach. DV-Hop count uses a technique based on distance vector routing. It uses the hop count between sensor nodes and anchors to infer the distances among them. In general, Range-based solutions have some hardware requirements, but can provide more accurate location estimates as compared to range-free solutions.

There are also few location discovery systems, which exploit ultrasonic signals. Active Bat System (Ward, 1997) was one of the first systems to use ultrasound time-of-arrival technique to provide the physical position of humans and objects in an office environment. Cricket Location Support System (Priyantha, 2000) is also an ultrasound-based systems providing user-centric location support for ubiquitous applications. A key reason for ultrasound's popularity in positioning systems is the relatively slow speed of sound as compared to radio signals. The downside to using ultrasound is its susceptibility to obstructions, echoes from hard surfaces and noise from everyday objects such as keys or plastic bags (McCarthy, 2006).

Authors of GPS-Free node localization (Akcan, 2006) proposed an algorithm for node localization based on relative motion of neighboring nodes without an infrastructure of GPS or anchor points. The downside of this algorithm is that it has a hardware requirement stating that every node must have a compass pointing north. Second thing, it requires that each node has to move a specific distance in a specific direction with respect to north, which makes it inapplicable in many deployments of sensor networks.

B. Routing Protocols

Routing in WSNs is challenging due to several characteristics that differs them from traditional wired and wireless networks. These include dense deployment of sensor nodes, significant data redundancy, limited bandwidth and limited transmission power (Akcan, 2006), etc.

Routing protocols can be categorized as data-centric and hierarchical protocols. Data-centric protocols are query-based and depend on the naming of desired data, which helps in eliminating many redundant transmissions. In data-centric routing, the sink sends queries to certain regions and waits for data from the sensor located in the selected regions.

Sensor Protocols for Information via Negotiation (SPIN) (Heinzelman, 1999) is the first data-centric protocol, which considers data negotiation between nodes in order to eliminate redundant data and save energy. The idea behind SPIN is to name the data using high level descriptors or meta-data. Before transmission meta-data are exchanged among sensors via a data advertisement mechanism, which is the key feature of SPIN. One of the advantages of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbor.

Directed diffusion (Intanagonwiwat, 2000) is an important milestone in the data-centric routing research of sensor networks. The idea aims at diffusing data through sensor nodes by using a simple attribute-based naming scheme for the data. Directed diffusion differs from SPIN in terms of on-demand data querying mechanism (Akcan, 2006)

In directed diffusion, the sink queries the sensor nodes for a specific data by flooding some tasks. While in SPIN, sensors advertise the

availability of data allowing interested nodes to query that data.

Advantages: Since directed diffusion is data centric, all communication is neighbor-to-neighbor with no need of addressing mechanism. Disadvantages: It cannot be applied to all sensor network applications, since it is based on a query-driver data delivery model. The applications that require continuous data delivery to the sink will not work efficiently with a query driven on demand data model. Therefore, directed diffusion is not a good choice as a routing protocol for the applications such as environmental monitoring. Moreover, this approach has limited reliability and energy efficiency because, if a path breaks, the sinks have to rebuild a new path, which will generate much traffic (Akcan, 2006).

Some other data centric protocols include rumor routing, Constrained Anisotropic Diffusion Routing (CADR), ACtive QUery forwarding In sensoR nEtworks (ACQUIRE), etc.

Hierarchical protocols aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy. Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman, 2000) is one of the first hierarchical routing approaches for sensor networks. The idea proposed in LEACH has been an inspiration for many hierarchical routing protocols. In LEACH, the idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. This saves energy since the transmissions is only done by such cluster heads rather than all sensor nodes. LEACH is completely distributed approach, so it does not require any global knowledge of network. Since LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink, therefore, it is not applicable to networks deployed in large regions.

Power-Efficient GAthering in Sensor Information Systems (PEGASIS) (Lindsey, 2002) is an improvement of the LEACH protocol. Rather than forming multiple clusters, PEGASIS forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (Sink). Gathered data moves from node to node, aggregated and eventually sent to the base station. PEGASIS differs from LEACH in the way as it uses multi-hop routing by forming chains and selecting only one node to transmit to the base station instead of using multiple nodes.

Some other hierarchical protocols include Hierarchical-PEGASIS, Threshold sensitive Energy Efficient sensor Network protocol (TEEN), Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN), etc.

C. Query Processing and Data Gathering

This section covers a review of some well known approaches taken towards the query processing and data gathering for sensor networks. These include Directed diffusion, Cougar, TinyDB and TASK, etc.

1. Directed Diffusion

Directed diffusion (Intanagonwiwat, 2000) is a well-known data aggregation paradigm for WSNs based on multi-path routing. The idea aims at diffusing data through sensor nodes by using a naming scheme for data interests. One of several paths is established between sink and sources by reinforcement, utilizing interest and gradients. The sink resends the original interest message through the selected path.

2. Cougar

Yao, *et. al.,* (2002) proposed Cougar at Cornell University. The approach adopted in Cougar is to treat the sensor network as a distributed database where data collection is performed using declarative quires, allowing the user to focus on the data itself, rather than data collection. Given a user query, a central query optimizer generates an efficient query plan aimed at minimizing resource usage within the network. The sensors sense data and then transmit the data, which matches with some criteria, to the base-station. The amount of data transferred to the base station is further minimized by doing some level of in-network processing.

3. TAG

Madden, *et al.,* (2002) proposed Tiny AGgregation (TAG) service for ad hoc sensor networks. TAG is first attempt at a distributed execution of queries in sensor networks. TAG has two limits: First, it deals with only aggregation queries. Secondly, queries are sent to all nodes, even also to those nodes that have not useful data, thus wastes energy and bandwidth. However, TAG also provides several advantages, e.g. transmission load is the same on any node no matter what their level is in the routing tree, thus power consumption is uniform on each node and it has the ability to tolerate disconnections and loss (Akcan, 2006). TAG operates

as follows: users send queries from sink. As query propagates in the network, it builds a tree rooted at sink. Sensors route data back towards the user through already established routing tree rooted at the base station. As data flows up this tree, it is aggregated according to an aggregation function and value-based partitioning specified in the query (Madden, 2002).

4. TinyDB

Madden, *et al.,* (2005) developed TinyDB, a distributed acquisitional query processor, at Intel Research Berkeley and UC Berkeley, which runs on each node in a sensor network. TinyDB extends the TAG approach to cover maximum types of queries. It facilitates users to query a sensor network using SQL like queries. It is designed for extracting information from sensors (Berkeley Mica motes) running TinyOS operating system. When queries are propagated to the network, a tree is formed which is used to route data back to the base station.

Amato, *et al.,* (2004) in their survey paper identified some problems in existing data management approaches. They discussed that TAG and TinyDB do not address the issue of what doing if data gets lost because the receiver is not hearing for any reason, such as interference, lack of energy, etc. Authors (Amato, *et al.*, 2004) suggested that some mechanism for buffering might be introduced to save data whenever the receiver is disconnected so that it can receive the data when it is connected again.

5. Tiny Application Sensor Kit (TASK)

Buonadonna, *et al.,* (2005) developed TASK, which provides a suite of java based logging, configuration, and visualization tools to assist in sensor network deployment (Buonadonna, 2005) TinyDB is the core of the TASK. In other words, we can also say that TASK provides a user-interface and relational database interface for collecting data from TinyDB.

Xia, *et al.,* (2006) proposed similarity-aware query processing SAQP scheme that exploits previous queries information within the sensor network. The proposed approach utilizes past query results to answer future similar queries. Through simulations, authors demonstrate that their SAQP scheme reduces energy consumption on queries with negligible increase in response time and without compromising the quality of data.

3. PROBLEM STATEMENT

This section presents the research direction towards one of the key issue discussed in previous section and guidelines for others to carry out the research in this domain.

As stated in previous section, there has been done an immense work on discovery of physical location/position of sensors in WSNs, however, there are many sensor network applications, which do not require the exact physical position of sensors; instead, these are more concerned with the sensed data and area based location accuracy. Examples of such applications include monitoring patients and tracking doctors in the hospitals, forest fire and flood detection, etc. In the view of these facts, we advocate that there is still lots of research potential in the area of localization of sensor networks. We believe that we need protocols and models that efficiently provide mechanisms for location detection of sensor nodes based on semantic information. Consequently, we have proposed a model along with a protocol, which discovers sufficiently accurate location information for the above mentioned WSNs applications and also generates location semantics, so that application doesn't require further processing to interpret it (for getting location semantics).

4. SOLUTION

Our work is different from others in two ways: First, we are proposing semantic localization for sensor networks, so that sensors not only know their relative address and sensed values, but also the location semantics, such as building, floor and room, the sensor is located in. Secondly, we are proposing to incorporate the data gathering/ reporting feature within the proposed model. From the literature survey presented in section 2, it is clear that there is lot of work on semantics in general, but in past there was less emphasize on semantic localization in the field of WSNs. The methodology how proposed system will work is given in subsequent sections.

A. Research Methodology

Fig. 2-4 demonstrate the working mechanism of the proposed model. The red boxes (5A23, 5A22, 5A21) are brokers and bit more powerful than other ordinary nodes. Blue box (Corridor) is a sink (also acts as a broker) and all other green boxes indicate ordinary sensors.

The proposed model is divided into two phases (1) Initialization/Update phase, and (2) Operate phase. In first phase, the initial location discovery of sensor nodes and base station takes place along with associating semantics with it. This phase is also responsible for maintaining and updating location information in case any change occurs in the location

of any sensor node(s). We also termed this phase as localization. The second phase is data gathering/reporting phase. Once localization phase is completed, this phase provides data collection or reporting feature.

1) Assumptions/Key Points

- We are suggesting to consider the publish/subscribe mechanism for communication; however, other models can also be used in practical implementations of the proposed model.
- Applications subscribe for particular interest at sink. Then sink is responsible for responding to the application, as soon as required data is available.
- Sink already know its location programmatically (or by GPS) and all brokers are in the range of sink/base station.
- Semantic dictionary (engine) is loaded into sink and all brokers, when system is initialized.
- Localization occurs, in two steps: First between sink and brokers. Second between brokers and nodes.
- All sensor nodes are assigned a semantic ID during the localization phase. Brokers are responsible for this task. For semantics, it is possible to use an existing ontology, such as OWL, RDF, etc or one can create a simple high-level naming scheme.
- Nodes send data to the nearest broker when they found a change in previously sensed data. Thus, all brokers keep updated information being sent by any sensor node(s) within their range.

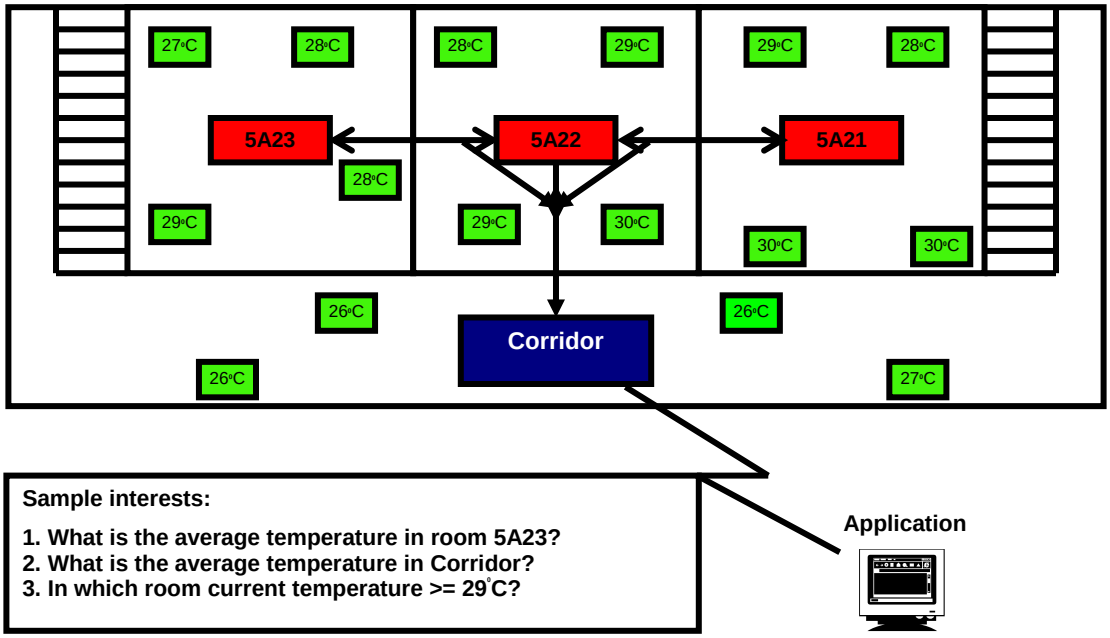


Fig. 2: A simple scenario to demonstrate the proposed model

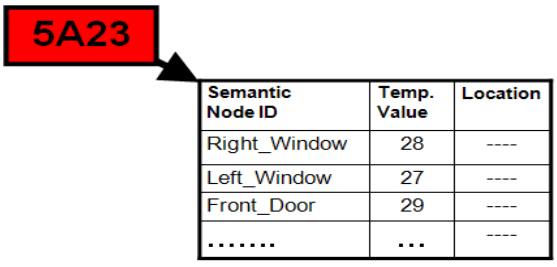


Fig. 3: Every broker monitors and keeps the record of semantic information of sensor nodes within its range.

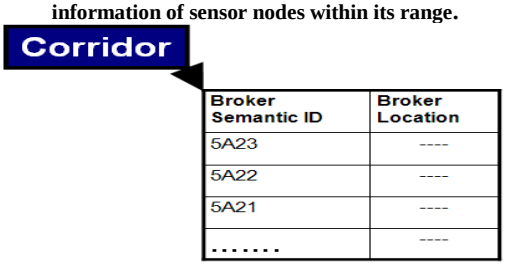


Fig. 4: Sink keeps record of sensors in its region (like brokers). Moreover, it has also an additional table to keep the record of brokers.

2) Algorithm

As stated in previous sub-section, semantic dictionary must be loaded into base station and brokers on system initialization. Further, base station must aware of its physical position programmatically or by other means, e.g. GPS. Once these requirements are met, the proposed algorithm works as stated below:

1. Base station broadcast beacon (sends invitation) with its physical position information for sensor nodes and brokers in the range to register (detect their locations) them at the base station.

2. In response, sensor nodes and brokers calculate their position information using RSSI approach and send it back to the base station.

3. Base station performs mapping to generate the semantic name for each sensor node and brokers in the range with reference to itself using semantic dictionary installed on it.

4. Base station broadcasts location information for sensor nodes and brokers in the range so that all the sensor nodes and brokers will be aware of their neighbors for in-network processing/communication (if required).

5. Base station sends beacons periodically (say for example every 2 or 3 minutes) to detect the CHANGE in topology.

6. If, change found (i.e. any sensor or broker added, moved or failed), it reacts accordingly and try to self-organize/self-configure the network.

7. When a node fails, base acknowledges all other nodes and brokers in range about the failure of particular node.

8. Similarly, when a node or a broker is added, base station performs localization operation once again automatically.

9. All brokers repeat the same localization technique (step 1 to 8) for sensor nodes in their range.

5. DISCUSSION

In previous section, we highlighted the problem of localization in WSNs from semantic locations point of view along with the proposed model as one of its solution. We advocated that there are many sensor network applications, which heavily rely on location information. For example considering the scenario discussed in this paper previously, sensor network applications might be interested in to know:

- What is the average temperature in Pevensey-II?
- In which room of Pevensey-II, current temperature is greater than 25^0C?
- Retrieve the current readings of temperature sensors in room 5A23
- How many sensors in Sussex House detect movement?
- Is lecture going on in room 2A11 of Pevensey-I?

In all of above queries, application is not concerned with exact physical locations, which are in the form of numbers, but it is interested in name-based (high-level) data. As stated, there is lot of literature, which discusses location estimation of sensor nodes, however, there has been less emphasize in past on such localization approaches, which consider the semantic localization in WSNs. Thus, it has been burden on application to interpret the received raw data into some useful location information. Towards, this, we presented the theoretical model as one of the solution to this problem. However, the practical implementation of the proposed model is not the focus of this paper. Consequently, the practical results are out of the focus of this paper.

6. CONCLUSION

Wireless Sensor Networks (WSNs) composed of very large number of small, inexpensive and low power sensing devices, capable of sensing, processing and communicating with each other to carry out the required task. It has many emerging and attracting applications with wide deployment in both military and commercial sectors; however, it is not a fully mature field yet, so research is on going in a variety of topics. Some open research issues include localization, routing protocols, topology control, design of middleware architectures, development of new simulation and debugging tools, etc. In this paper, we presented the survey of localization, routing and data gathering in WSNs. Further, we emphasized and highlighted the issue of localization along with providing a model as one of the solution to this problem.

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