TRLabs Report

on

Current Researches on Sensor Networks

By

Sayed Ahmed
sayed@cs.umanitoba.ca

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Supervisor
Prof. Rasit M. Eskicioglu
rasit@cs.umanitoba.ca

Abstract

Technological advances in electronics have led to highly efficient, low powered, integrated communication devices and sensors. Sensors can be spread throughout a region to build a network for many applications such as environmental observations, habitat monitoring, protecting a region from intruders, military applications and so on. Sensor networks have become a very active topic of research due to its emerging importance in many personal, home, industry, agriculture, and medical applications. This report demonstrates a wide survey of sensor networks research. The report identifies the research areas of sensor networks, presents the past researches in these areas also draws some conclusions about future and further research directions.

1 Introduction

Recent advances in electronics and wireless communications have led to the development of tiny, low-cost, low-power and active sensors. Besides, there are large, high bit rate sensors such as web cam, pressure gauge and so on. These large sensors are utilized in many practical sensing applications such as free parking space finding applications. Also neural network and artificial engineers are trying to embed some intelligence in today's sensors. All of these types of sensors observe a physical phenomenon such as temperature, humidity, and do some processing and filtering on the sensed data. These sensors are spread over a region to build a sensor network and the sensors in a region co-operate to each other to sense, process, filter and routing. Usually a sensor node contains a sensing, a processing and a communication unit where in some sensor nodes mobility unit and location detection units are embedded.

Like the traditional computer networks sensor networks can also be analyzed in terms of seven OSI layers as they are more or less a must analysis points in any kind of networks with some different attentions. So the existing researches on the layers of sensor networks have been discussed in this report with some analogy and differences with traditional computer networks.

For tiny, low power sensors the most important issue is the power consumption. To make such sensor networks useful power consumption issues must be addressed. In a word, all protocols and applications for sensor networks must consider the power consumption issue and try to the best to minimize power consumption. Existing power saving research on sensor networks are also addressed in this report.

Sensor networks are somewhat different from traditional networks as sensor nodes are very prone to failures. As sensor nodes die the topology of the sensor networks changes very frequently. Therefore, the algorithms for sensor network should be robust and stable. The algorithms should work in case of node failure. When mobility is introduced in the sensor nodes, maintaining the robustness and consistent topology discovery become much difficult. Besides, there are huge amount of sensors in a small area. Most sensor networks use broadcasting for communication while traditional and adhoc networks use point to point communication. Hence the routing protocol should be designed considering these issues as well.

The report addresses the research issues in sensor networks under the following categories.

- Design and Architecture
- Physical Layer
- Protocols
- Power Management
- MAC/Data Link Layer
- Network Layer
  - Addressing Mechanism
  - Routing
  - Others
- Distributed Network
  - Overview
  - Algorithms
  - Location Mechanism/Deployment/Target Tracking
  - Topology Discovery
  - Time Synchronization
- Application Layer
- Operating System
- Simulation
- Query Processing

2 Sensor Network Architecture and Design

In this section, we address the researches on the overall architecture and design proposed for sensor networks. The analysis and study of architectures help to know the key design requirements for sensor networks. The analysis also helps in the perfect design of each individual component of sensor networks.

Some important and extensive design issues of sensor networks are discussed in [21]. The issues addressed are example design points such as hardware organization, power characteristics, and tiny micro-threading OS issues such as OS design, OS components, OS components type, Effect of putting components together. Besides, sensor characteristics and evaluation and architectural implications of sensor characteristics are explained [21].

A sensor information networking architecture, called SINA is proposed in [20]. SINA provides an architecture that helps in "querying, monitoring, and tasking" of sensor networks. SINA modelled sensor networks as a collection of "massively distributed objects". SINA acts as a middle ware that helps in "adaptive organization" of sensor information. The SINA kernel provides a set of configuration and communication primitives that enable scalable, robust, and energy-efficient organization and interactions among sensor objects. On top of the SINA kernel there is a programmable substrate that follows the spreadsheet paradigm and provides mechanisms to create associations among sensor nodes. Users then access information within a sensor network using declarative queries and perform tasks using programmable scripts. Issues concerning interworking between stationary sensor networks and mobile nodes were also addressed [20]. An integrated architecture for co-operative sensing and networking is addressed in [1]. It is argued that a data handling architecture for these devices should incorporate their extreme resource constraints - energy, storage and processing and spatiotemporal interpretation of the physical world in the design, cost model, and metrics of evaluation [8]. DIMENSIONS, a system that provides a unified view of data handling in sensor networks, incorporating long-term storage, multi-resolution data access and spatiotemporal pattern mining [8] is presented.

An Example network architecture is presented in [3] and investigation of some of the architectural challenges by systems that are massively distributed, physically coupled, wirelessly networked and energy limited are presented in [9]. Review of the key elements of sensor networks, outlines of the research challenges they present to the mobile networking are presented in [14]. Another network architecture design and implementation issues are discussed in [5]. System architecture for sensor network is discussed [11]. A configurable architecture, energy-conscious system-design and implementation methodology that will lead to radio nodes that are two orders of magnitude more efficient than existing solutions is presented in [23].

Rabaey et al. in [15] present a scalable network architecture for using wireless networked in combination with wireless ethernet networks to provide a complete end to end solution to narrow the gap between low level information and context awareness. Mini et al. in [12] propose a network state model to represent the behavior of a sensor node. Key design issues of future micro sensor systems including the network protocols required for collaborative sensing and information distribution is discussed in [20].

Sensor networks are severe power constraints, and typically sample periodically and push immediately, keeping no record of historical information. These limitations make traditional database systems inappropriate for queries over sensors. The Fjords architecture for managing multiple queries over many sensors are proposed, and it is shown how it can be used to limit sensor resource demands while maintaining high query throughput [18] The architecture was evaluated using traces from a network of traffic sensors deployed on Interstate 80 near Berkeley and present performance results that show how query throughput, communication costs, and power consumption are necessarily coupled in sensor environments [18].

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3 Physical Layer

A signal processing method for event detection have been developed with low power, parallel architectures that optimize performance for unique sensor system requirements [25]. Signal processing architectures for sensor networks are also provided in [24, 26, 30].

Implementation of a parallel data paths with shared arithmetic elements enabling high throughput at low clock rate [25] is presented. This method has been used to implement a micro sensor spectrum analyzer for a 200 sample/s measurement system [25].

A new object-relational data type is introduced termed as GADT (Gaussian ADT). GADT models physical data as gaussian pdfs [28] and shows that existing index structures can be used as fast access methods for GADT data. it also presents a "measure-theoretic" model of probabilistic data and evaluate GADT in its light [28].

A physical layer driven approach to designing protocols and algorithms is proposed in [31]. The paper [31] first presents a hardware model for the wireless sensor node and then introduces the design of physical layer aware protocols, algorithms, and applications that minimize energy consumption of the system [31]. The approach prescribes methods that can be used at all levels of the hierarchy to take advantage of the underlying hardware [31]. It also shows how to reduce energy consumption of non-ideal hardware through physical layer aware algorithms and protocols [31]. Micro power data converter is discussed in [24]. Digital signal processing systems, weak inversion CMOS RF circuits are also designed in [24]. This RF circuit utilizes low power [24]. Some physical layer principles are presented in [30]. In [27] it is identified the opportunities and challenges for distributed signal processing for sensor networks.

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4 Protocols

An energy scalable protocols for battery-operated micro sensor networks is studied [38]. Protocols for self organization of a wireless sensor network is studied in [37]. Shankar et al. in [34] provide a cluster based protocol in which only a small fraction of the nodes make expensive long distance base station transfers [34] Shankar et al. in [34] also proposed a tree based protocol. A measurement of energy efficiency shows that cluster based method is better than tree based protocol. Mentionable, Shankar et al. studied the algorithms using bio sensors having small but continuous power supply [34]. A physical layer driven approach to designing protocols and algorithms is proposed [35]. The paper introduces the design of physical layer aware protocols, algorithms, and applications that minimize energy consumption of the system. An energy efficient protocol to initialize a sensor node in a WSN is also presented in [35]. Power aware multi access protocol with signalling for adhoc networks is provided in [32].

Harsh environment with severe resource constraints requires an application-specific protocol architecture, rather than the traditional layered approach, to obtain the best possible performance [33]. The study in [33] develops LEACH (Low-Energy Adaptive Clustering Hierarchy), an architecture for remote micro sensor networks that combines the ideas of energy-efficient cluster-based routing and media access together with application-specific data aggregation to achieve good performance in terms of system lifetime, latency, and application-perceived quality. This approach improves system lifetime by an order of magnitude compared to general-purpose approaches when the node energy is limited [33]. The study in [33] also develops an unequal error protection scheme for MPEG-4 compressed video delivery that adapts the level of protection applied to portions of a packet to the degree of importance of the corresponding bits. This approach obtains better application-perceived performance than current approaches for the same amount of transmission bandwidth [33]. These two systems show that application-specific protocol architectures achieve the energy and latency efficiency and error robustness needed for wireless networks [33].

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5 Power Management

For sensor networks, power consumption is the most important thing to consider. All algorithms, protocols and applications should use minimum energy. An effort where the principle idea is to maximize computational quality for a given energy constraint is [48]. The desirable energy-quality behavior of algorithms is discussed. Subsequently the energy-quality scalability of three distinct categories of commonly used signal processing algorithms (viz. filtering, frequency domain transforms and classification) are analyzed on the StrongARM SA-1100 processor and transformations [48]. The notion of power-awareness is defined in [41] where it showed that power awareness is a distinguish concept from low power concept [41]. To propose a systematic methodology that enhances power awareness and finally to illustrate the impact of this, [41] also shows energy efficiency of this systematic method [41]. The fundamental question concerning the limits of energy efficiency of wireless sensor networks - what is the upper bound on the lifetime of a sensor network that collects data from a specified region using a certain number of energy-constrained nodes is addressed [41]. By employing a combination of theory and extensive simulations of constructed networks, the paper showed that in all data gathering scenarios presented, there exist networks which achieve lifetimes equal to or >85% of the derived bounds. Hence, depending on the scenario, the bounds are either tight or near-tight [41].

A network state model to represent the behavior of a sensor node is proposed [46].In [46] Mini et al. also showed how this model can be used to predict the energy consumption by a sensor node and consequently to construct an energy map of the network, comparison with naive style. A micro power data converter is proposed in [39] that also designed this RF circuit to utilize low power. The paper [43] reports advances in low power systems spanning network design, through power management. Besides it provides low power mixed signal circuits, highly integrated RF network interfaces, particular attention is focused on methods for low power RF receiver systems [43]. This paper presents an overview of the key technologies required for low-energy distributed micro sensors [45]. Some low energy electronics are proposed in [3]. Also power system design and energy harvesting techniques are provided [3].

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Data Link/MAC Layer

The following sections will provide different data link layer strategies for sensor networks and identify key requirements and future research requirements in data link layer for sensor networks.

5.1 Different MAC Protocols

In this section a brief discussion of different MAC protocols is provided.

5.1.1 SMACS and EAR

SMACS [97] is used for network start-up and link layer organization, and the EAR provides continuous effective connection of mobile nodes in a sensor network.

SMACS does not use any local or global master nodes to discover their neighbors and establish transmission/reception schedules for communication. The neighbor discovery and channel assignment phases are combined so that by the time nodes hear all their neighbors, they would have formed a connected network. A communication link uses frequency hopping spread spectrum since, the available bandwidth can be expected to be much higher than the maximum data rate for sensor nodes avoiding network-wide synchronization, although communicating neighbors in a subnet need to be time synchronized. Power conservation is achieved by using a random wake-up schedule during the connection phase and by turning the radio off during idle time slots.

5.1.2 EAR

The EAR protocol [97] attempts to offer continuous service to the mobile nodes under both mobile and stationary conditions. Here, the mobile nodes assume full control of the connection process and also decide when to drop connections, thereby minimizing messaging overhead. The EAR is transparent to the SMACS, so that the SMACS is functional until the introduction of mobile nodes into the network. In this model, the network is assumed to be mainly static, i.e., any mobile node has a number of stationary nodes in its vicinity. A drawback of such a time-slot assignment scheme is the possibility that members already belonging to different subnets might never get connected.

5.1.3 S-MAC

S-MAC [74], a medium-access control (MAC) protocol designed for wireless sensor networks. S-MAC applies message passing to reduce contention latency for power saving nodes periodically sleep for power saving sleep when others transfer data,S-MAC also sets the radio to sleep during transmissions of other nodes. Unlike PAMAS, it only uses in-channel signaling [74].

5.1.4 RMST

Reliable data transport in wireless sensor networks is a multifaceted problem influenced by the physical, MAC, network, and transport layers. Because sensor networks are subject to strict resource constraints and are deployed by single organizations, they encourage revisiting traditional layering and are less bound by standardized placement of services such as reliability. This paper presents analysis and experiments resulting in specific recommendations for implementing reliable data transport in sensor nets. To explore reliability at the transport layer,in [98] Stann et al. presents RMST (Reliable Multi-Segment Transport), a new transport layer for Directed Diffusion. RMST provides guaranteed delivery and fragmentation/reassembly for applications that require them. RMST is a selective NACK-based protocol that can be configured for in-network caching and repair.

5.1.5 Aloha Based

Hoiydi et al. in [68] presents an analysis of the performances of the Aloha protocol combined with the preamble sampling technique. This protocol is intended for low power sporadic communications in an ad hoc wireless network of sensors. The delay performances and the resulting power consumption and lifetime are computed analytically. The benefits of using CSMA instead of Aloha are indicated. The lifetime that can be expected by a node with a single alkaline LR6 battery is given for the different protocols in function of the interval between successful transmissions. Lifetime of years can be expected using Aloha with preamble sampling if the traffic is low. This protocol can be used to transmit sporadic data traffic or the signaling traffic needed to synchronize a network into a TDMA schedule.

in [50] Adireddy et al. proposes a variant of the Slotted ALOHA protocol for medium access where the transmit probability is chosen as a function of the channel state. Also in [50] Adireddy et al. introduces the notion of asymptotic stable throughput and characterize the achievable asymptotic stable throughput through the use of channel state information. As an example, considered the application of the results to sensor networks.

5.1.6 CSMA Based Medium Access

A CSMA based MAC scheme for sensor networks is presented in [104]. the MAC protocol for sensor networks must be able to support variable, but highly correlated and dominantly periodic traffic. Any CSMA based medium access scheme has two important components, the listening mechanism and the backoff scheme. simulations [104] show the constant listen periods are energy efficient and the introduction of random delay provides robustness against repeated collisions. Fixed window and binary exponential decrease backoff schemes are recommended to maintain proportional fairness in the network.

A phase change at the application level is also advocated to get over any capturing effects. It is proposed in this work that the energy consumed per unit of successful communication can serve as a good indicator of energy efficiency.

An adaptive transmission rate control (ARC) scheme, that achieves medium access fairness by balancing the rates of originating and route-thru traffic is also discussed here. This ensures that nodes closer to the access point are not favored over those deep down into the network. The ARC controls the data origination rate of a node in order to allow the route-thru traffic to propagate. A progressive signalling mechanism is used to inform the nodes to lower their data originating rate. The ARC uses a linear increase and multiplicative decrease approach. While the linear increase leads to more aggressive channel competition, the multiplicative decrease controls transmission failure penalty. Since dropping route-thru traffic is costlier, the associated penalty is lesser than that for originating data transmission failure. This ensures that route-thru traffic is preferred over the originating traffic. The computational nature of this scheme makes it more energy efficient than handshaking and messaging schemes using the radio. The ARC also attempts to reduce the problem of hidden nodes in a multihop network by constantly tuning the transmission rate and performing phase changes, so that periodic streams are less likely to repeatedly collide.

A CSMA/CD based micro-controller communication network for low-level control is presented in [61]. The "PICAR" [57, 58, 59] project is based on "Prometheus Prochip" experience and results. The goal is to design an embedded multi sensors collision avoidance system for automotive application.

5.1.7 Hybrid CSMA/Spread Spectrum

Simple CSMA and spread spectrum techniques are combined to trade off bandwidth and power efficiency [94].

5.1.8 Hybrid CSMA/TDMA

In [69] Hoiydi et al. presents an analysis of the performances of low power multiple access protocols designed for a network of wireless sensors. It considers the use of spatial TDMA for the transport of regular and frequent traffic and of a low power version of the nonpersistent CSMA protocol for the transport of rare signaling traffic. The low power version of CSMA is obtained by combining it with a preamble sampling technique. The delay performances and associated power consumption and lifetime are computed analytically. The power consumption of TDMA is computed as well, taking into account the power cost of keeping synchronized two nodes which have imprecise clocks. The lifetime that can be expected by a node with a single alkaline LR6 battery is given as a function of the desired average time interval between collision free transmissions on the TDMA and on the contention channels.

5.1.9 Hybrid TDMA/FDMA Based

This centrally controlled MAC scheme is introduced in [35] . In this work, the effect of non-ideal physical layer electronics on the design of MAC protocols for sensor networks is investigated. The system is assumed to be made up of energy constrained sensor nodes that communicate to a single, nearby, highpowered base station (¡10 m). Specifically, the machine monitoring application of sensor networks, with strict data latency requirements, is considered and a hybrid TDMA-FDMA medium access scheme is proposed. While a pure TDMA scheme dedicates the full bandwidth to a single sensor node, a pure FDMA scheme allocates minimum signal bandwidth per node. Despite the fact that a pure TDMA scheme minimizes the transmit on-time, it is not always preferred due to the associated time synchronization costs.

An analytical formula is derived in [35] to find the optimum number of channels which gives the lowest system power consumption. This determines the hybrid TDMA-FDMA scheme to be used. The optimum number of channels is found to depend on the ratio of the power consumption of the transmitter to that of the receiver. If the transmitter consumes more power, a TDMA scheme is favored, while the scheme leans toward FDMA when the receiver consumes greater power.

5.1.10 Convergecasting Tree Construction and Channel Allocation Algorithm (CTCCAA))

Most sensor applications involve both converge casting and broadcasting. The time taken to complete either of them has to be kept minimal. This can be accomplished by constructing an efficient tree for both broadcasting as well as converge casting and allocating wireless communication channels to ensure collision-free communication. There exist several works on broadcasting in multihop radio networks (a.k.a. ad hoc networks), which can also be used for broadcasting in WSNs. These algorithms construct a broadcast tree and compute a schedule for transmitting and receiving for each node to achieve collision-free broadcasting. Annamalai et al. in [53] shows that we need a new algorithm for applications, which involve both converge casting and broadcasting since the broadcast tree may not be efficient for convergecasting. So it propose a heuristic algorithm (convergecasting tree construction and channel allocation algorithm (CTCCAA)), which constructs a tree with schedules assigned to nodes for collision free convergecasting. The algorithm is capable of code allocation (direct sequence spread spectrum (DSSS)/ frequency hopping spread spectrum (FHSS)), in case multiple codes are available, to minimize the total duration required for convergecasting.In [53] Annamalai et al. also shows that the same tree can be used for broadcasting and is as efficient as a tree exclusively constructed for broadcasting.

5.1.11 Colorwave

In [100] Waldrop et al. presents Colorwave, a medium access control (MAC) protocol designed for wireless sensor networks such as radio frequency identification (RFID) reader networks. A network of readers will collaborate for a common application such as item-level monitoring in supply chain management. Readers may be deployed in an ad hoc manner, and readers must not interfere with one another's reader-to-tag communication. Colorwave capitalized on the localized nature of reader-to-tag communications to provide an on-line, distributed, and localized MAC protocol that minimized reader-to-reader interference.

5.1.12 A Dynamic Addressing Scheme

Schurgers et al. in [162, 95] proposes a dynamic MAC addressing scheme based on a distributed algorithm. The assigned addresses are reused spatially and represented by variable-length codewords. The scheme scales very well with the network size, rendering it well-suited for sensor networks with thousands or millions of nodes [162]. MAC addresses, which are vital in a shared medium, present a major overhead,particularly because they are traditionally chosen to be network-wide unique. Schurgers et al. also tries To tackle this overhead [162].

Sensor data typically consists of packets with small payloads due to which the MAC header is a significant and energy-expensive overhead. In [82] Kulkarni et al. presents a scheme that replaces conventional MAC addresses with dynamically assigned short link labels that are spatially reused. This would be useful in self-configuring sensor networks. Kulkarni et al. also presents an encoded representation of these labels for use in data packets and developed a distributed algorithm involving local exchange of control messages for the assignment of these labels. Simulation results demonstrate the scalability of the assignment algorithm and the encoded label representation. In typical scenarios, the MAC header is reduced by a factor of eight as compared to traditional MAC headers. They also show the conditions under which the energy savings outweigh the protocol overheads [82].

5.2 Power saving modes of operation

Regardless of which type of medium access scheme is used for sensor networks, it certainly must support the operation of power saving modes for the sensor node. Related works considering power saving in MAC are [107].

5.3 Error control

Two important modes of error control in communication networks are the forward error correction (FEC) and automatic repeat request (ARQ). To the best of our knowledge, the application of ARQ schemes is thus far unexplored in the regime of sensor networks, though many adaptive and low power versions are existent in literature for other mobile networks [86, 91]. The usefulness of ARQ in sensor network applications is limited by the additional re-transmission cost and overhead. On the other hand, decoding complexity is greater in FEC, as error correction capabilities need to be built-in. Considering this, simple error control codes with low-complexity encoding and decoding might present the best solutions for sensor networks. In the design of such a scheme it is important to have good knowledge of the channel characteristics and implementation techniques.

5.3.1 FEC

Reliable data communication can be provided either by increasing the output transmit power Pout or the use of suitable FEC. Since a sensor node has limited power resources, the former option is not feasible. So turn to FEC. As FEC can achieve significant reduction in the BER for any given value of Pout. However, we must take into account the additional processing power that goes into encoding and decoding. This processing power is drawn from the limited resources possessed by the node. This might be critical for sensor networks though it can be negligibly small in other wireless networks. If the associated processing power is greater than the coding gain, then the whole process in energy inefficiency and the system is better off without coding. On the other hand, FEC is a valuable asset in sensor networks, if the sum of the encoding and decoding processing powers is less than the transmission power savings. It is to be noted that all these computations and comparisons must be carried out for a given, in most cases application specific, BER. Though adaptive FEC has received some attention in other wireless networks, it remains largely unexplored in sensor networks. The impact of adapting packet size and error control on energy efficiency in wireless systems is investigated in [89]. In [96], the authors examine this issue for sensor networks. They assume a frequency nonselective, slow Rayleigh fading channel and use convolutional codes for FEC. Based on their analysis, they conclude that the average energy consumption per useful bit shows an exponential increase with the constraint length of the code and is independent of the code rate. Moreover, they found that FEC is generally inefficient if the decoding is performed using a micro-processor and recommend an on-board dedicated Viterbi decoder. To the best of our knowledge, other coding schemes remain unexplored. Simple encoding techniques that enable easy decoding might present an energy efficient solution for sensor networks.

5.3.2 Other Works

Contrary to present conjectures, the medium access control (MAC) based performance [93] studies reveales that battery capacity may not be used as the sole means for achieving energy-based fairness and system longevity for wireless mobile multi-hop ad hoc and sensor networks. Moreover, energy conservation may be attained only if valuable MAC (and PHY) input is passed to the network layer. Hence, Safwati et al. in [93] proposes two schemes, the objective of which is to enhance the operation of existing power-based multi-path routing protocols via cross-layer designs and optimal load assignments. the proposed schemes, namely, energy-constrained path selection (ECPS) and energy-efficient load assignment (E2LA), employ probabilistic dynamic programming techniques and utilize cross-layer interactions between the network and MAC layers. To the best of the authors' knowledge, this is the first time that MAC-originated information is used as the basis for achieving energy-efficient routing A Transmission Control Scheme for Media Access in Sensor networks.

Data link layer design for wireless sensor networks [109]. Medium Access Control With Co-Ordinated, Adaptive Sleeping for Wireless Sensor Networks [107]. MAC protocol design, that performs effective collision and overhearing avoidence [106]. Energy Efficient Modulation and MAC for Asymmetric RF Microsensor System [101].

Guo et al. targeted multi-hop wireless sensor networks in [94] and a set of low power MAC design principles have been proposed, also a novel ultra-low power MAC is designed to be distributed in nature to support scalability, survivability and adaptability requirements. Simple CSMA and spread spectrum techniques are combined to trade off bandwidth and power efficiency. A distributed algorithm is used to do dynamic channel assignment. A novel wake-up radio scheme is incorporated to take advantage of new radio technologies. The notion of mobility awareness is introduced into an adaptive protocol to reduce network maintenance overhead. The resulting protocol shows much higher power efficiency for typical sensor network applications. also in [101] an Energy Efficient Modulation scheme also a MAC for Asymmetric RF Microsensor System is presented.Flexible and Reliable Radio Communication Stack on Motes [106].

5.3.3 Future Directions

Though some medium access schemes have been proposed for sensor networks, the area is still largely open to research. So is the mainly unexplored domain of error control in sensor networks.

Key open research issues include [52]:

- MAC for mobile sensor networks: The proposed SMACS and EAR [97] perform well only in a mainly static sensor networks. It is assumed in the connection schemes that a mobile node has many static nodes as neighbors. These algorithms must be improved to deal with more extensive mobility in the sensor nodes and targets. Mobility issues, carrier sensing, and backoff mechanisms for the CSMA based scheme also remain largely unexplored.
- Determination of lower bounds on the energy required for sensor network self-organization.

- Error control coding schemes: Error control is extremely important in some sensor network applications like mobile tracking and machine monitoring. Convolutional coding effects have been considered in [35]. The feasibility of other error control schemes in sensor networks needs to be explored

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6 Network Layer: Addressing Mechanism

An address-free architecture is proposed for use in certain contexts where nodes or data are described by attributes other than addresses. Instead of using statically assigned addresses that are guaranteed to be unique, nodes randomly select probabilistically unique identifiers for each new transaction [110]. Another approach where nodes randomly select probabilistically unique identifiers for each new transaction is proposed [111]. It is shown how this randomized scheme can significantly improve the systems energy efficiency in contexts where that efficiency is paramount, such as energy-constrained wireless sensor networks. Benefits are realized if the typical data size is small compared to the size of an identifier, and the number of transactions seen by an individual node is small compared to the number of nodes that exist in the entire system [111].

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7 Network Layer: Routing

Advances in hardware for sensor nodes that combine sensing devices, embedded processors, and communication components have made the large-scale deployment of sensor networks a reality. Various sensor network applications ranging from monitoring to military applications require sensor nodes to collect data over a continuous time period and send data to the central node directly or co-operating with the data of other sensor nodes. Using an appropriate energy-efficient and fast routing strategy to deliver the data to the desired node definitely would make sensor networks effective and useful. In this paper, we attempt to identify the key routing techniques used in sensor networks, evaluate them in terms of efficiency, scalability, resource usage and applicability and outline the most challenging research directions. We start by identifying a set of design goals and challenges related to routing over sensor networks. The evaluation of the techniques is guided by the distinctive routing features of different routing protocols and their solutions to address these challenges in sensor networks. We conclude with the routing requirement for future applications with some possible integration items into existing routing algorithms.

7.1 Introduction

The advent of sensor technology will definitely explode the wide deployment of sensor networks that consists of tens to thousands of extremely small, low power sensor devices equipped with programmable computing, multiple sensing and communication capabilities. Sensor networks will become important nerve centers that monitor and actuate our physical environment. Sensors in a network can coordinate amongst themselves to achieve a larger sensing task. The sheer numbers of these sensors and the expected dynamics in these environments where power is limited, user queries are effectively continuous over time and long lived demands unique challenges in the design of unattended autonomous sensor networks. Integrated low-power sensing devices will permit remote object monitoring and tracking in many different applications: in the field (vehicle, equipment, personnel), the office building (projector, furniture, books) and the hospital ward (Syringes, bandages). The idea is to embed numerous distributed devices to monitor and interact with physical world. These devices will form an Ad hoc network amongst themselves and communicate the information to the end user. Collecting data and routing appropriate and needed data to the end user is a challenging issue in such a wireless battery operated small sensor networks. Sensor information are data centric and using traditional network protocols are not always appropriate or sufficient. Using IP protocol and related routing protocols are overhead for sensor networks as sensors can not tolerate extra overhead of maintaining and IP routing tables besides these are not mandatory in sensor networks. Because the only task is to send data to the end user. maintaining routing table in each sensor node from source to sink is an overhead. rather sensor nodes can interactively co-operate to find a route to the end user. definitely routing protocol should be robust, energy efficient, and use minimum time and create least traffic in the network.

7.2 Sensor Network Routing Challenges

- **Robustness:** Sensor nodes are mostly unattended and are not directly exposed to an user or end user. very often sensors are placed in a forest, hilly area or in the bed of a river or sea. Besides Sensor networks exist with the ratio of thousands of nodes per user. At such ratios, it is impossible to pay special attention to any individual node. Thus Robustness of software is most important.
- **Stability against task dynamics:** Mentioned before that sensors may be inaccessible, either because they are embedded in physical structures, or thrown into inhospitable terrain. Thus for such system to be effective, it must provide stability.
- **Scalability:** The mechanism must scale to several thousands of sensor nodes in the sensor field.
- **Energy Efficiency:** Wireless communication, over relatively short distance, consumes significant energy. Since sensor nodes are battery operated, communication mechanism for information dissemination should be energy efficient.

7.3 Communication in Sensor Networks

Communication requirements in sensor networks are significantly different from traditional wired and wireless networks design leading to a different set of design issues. The design has the following features:

- **Data-Centric:** Unlike traditional networks, a sensor node doesn't need an identity (e.g., an address). That is, sensor network applications are unlikely to ask the question: What is the temperature at sensor 27? Rather, applications focus on the data generated by sensors. Data is named by attributes and applications request data matching certain attribute values. So, the communication primitive in this system is a request: Where are nodes whose temperatures recently exceeded 30 degrees?

- **Application-Specific:** Traditional networks are run a wide variety of applications. But it is reasonable to assume that sensor networks can be tailored to the sensing task at hand. In particular, this means that intermediate nodes can perform application-specific data aggregation and caching.

7.4 Metrics for a Routing Algorithm

- **Maximum available power (PA) route:** The route that has maximum total available power is preferred. The total PA is calculated by summing the PAs of each node along the route. But it may not be always the most power efficient route.

- **Minimum energy (ME) route:** The route that consumes ME to transmit the data packets between the sink and the sensor node is the ME route.

- **Minimum hop (MH) route:** The route that makes the MH to reach the sink is preferred.

- **Maximum minimum PA node route:** The route along which the minimum PA is larger than the minimum PAs of the other routes is preferred.

- **Data Centric:** Another important issue is that routing may be based on data centric. In data-centric routing, the interest dissemination is performed to assign the sensing tasks to the sensor nodes. There are two approaches used for interest dissemination: sinks broadcast the interest , and sensor nodes broadcast an advertisement for the available data and wait for a request from the interested sinks. The data-centric routing requires attribute based naming . For attribute-based naming, the users are more interested in querying an attribute of the phenomenon, rather than querying an individual node. For instance,"the areas where the temperature is over 70 degree F" is a more common query than "the temperature read by a certain node". The attribute-based naming is used to carry out queries by using the attributes of the phenomenon. The attribute-based naming also makes broadcasting, attribute-based multi-casting, geo-casting and any-casting important for sensor networks.

7.5 Routing Algorithms

In this section different routing algorithms are discussed.

7.5.1 Flooding

Flooding [123, 124, 156, 165] is an old technique that can also be used for routing in sensor networks. In flooding, each node receiving a data or management packet repeats it by broadcasting, unless a maximum number of hops for the packet is reached or the destination of the packet is the node itself. Flooding is a reactive technique, and it does not require costly topology maintenance and complex route discovery algorithms. However, it has several deficiencies [159] such as:

- **Implosion:** Implosion is a situation where duplicated messages are sent to the same node. For example, if sensor node A has N neighbor sensor nodes that are also the neighbors of sensor node B, the sensor node B receives N copies of the message sent by sensor node A.
- **Overlap:** If two nodes share the same observing region, both of them may sense the same stimuli at the same time. As a result, neighbor nodes receive duplicated messages.
- **Resource blindness:** The flooding protocol does not take into account of the available energy resources. An energy resource aware protocol must take into account the amount of energy available to them at all time.

7.5.2 Gossiping

A derivation of flooding is gossiping [134, 152] in which nodes do not broadcast but send the incoming packets to a randomly selected neighbor. A sensor node randomly selects one of its neighbors to send the data. Once the neighbor node receives the data, it selects randomly another sensor node. Although this approach avoids the implosion problem by just having one copy of a message at any node, it takes long time to propagate the message to all sensor nodes.

7.5.3 Sensor Protocols for Information via Negotiation(SPIN)

A family of adaptive protocols called SPIN [137, 148] is designed to address the deficiencies of classic flooding by negotiation and resource adaptation. The SPIN family of protocols are designed based on two basic ideas: sensor nodes operate more efficiently and conserve energy by sending data that describe the sensor data instead of sending the whole data, e.g., image, and sensor nodes must monitor the changes in their energy resources.

SPIN has three types of messages, i.e., ADV, REQ, and DATA. Before sending a DATA message, the sensor broadcasts an ADV message containing a descriptor, i.e., meta-data, of the DATA. If a neighbor is interested in the data, it sends a REQ message for the DATA and DATA is sent to this neighbor sensor node as shown in respectively. The neighbor sensor node then repeats this process a. As a result, the sensor nodes in the entire sensor network, which are interested in the data, will get a copy. Note that SPIN is based on data-centric routing where the sensor nodes broadcast an advertisement for the available data and wait for a request from interested sinks.

Kulik et al. in [148], Presents a family of adaptive protocols, called SPIN (Sensor Protocols for Information via Negotiation), that efficiently disseminate information among sensors in an energy-constrained wireless sensor network. Nodes running a SPIN communication protocol name their data using high-level data descriptors, called meta-data. They use meta-data negotiations to eliminate the transmission of redundant data throughout the network. In addition, SPIN nodes can base their communication decisions both upon application specific knowledge of the data and upon knowledge of the resources that are available to them. This allows the sensors to efficiently distribute data given a limited energy supply. In [148] four specific SPIN protocols: SPIN-PP and SPIN-EC, which are optimized for a point-to-point network, and SPIN-BC and SPIN-RL, which are optimized for a broadcast network are analyzed with simulation results.

Comparing the SPIN protocols to other possible approaches, it is found that the spin protocols can deliver 60% more data for a given amount of energy than conventional approaches in a point to point network and 80% more data for a given amount of energy in a broadcast network. Also in terms of dissemination rate and energy usage the spin protocols perform close to the theoritical optimum in both point to point and broadcast networks.

7.5.4 Sequential Assignment Routing (SAR)

SAR [97], a set of algorithms, which perform organization, management and mobility management operations in sensor networks. Self-organizing MAC for sensor networks (SMACS) is a distributed protocol that enables a collection of sensor nodes to discover their neighbors and establish transmission/reception schedules without the need for a central management system. The eavesdrop and register (EAR) algorithm is designed to support seamless interconnection of the mobile nodes. The EAR algorithm is based on the invitation messages and on the registration of stationary nodes by the mobile nodes. The SAR algorithm creates multiple trees where the root of each tree is an one hop neighbor from the sink. Each tree grows outward from the sink while avoiding nodes with very low QoS (i.e., low throughput/high delay) and energy reserves. At the end of this procedure, most nodes belong to multiple trees. This allows a sensor node to choose a tree to relay its information back to the sink. There are two parameters associated with each path, i.e., a tree, back to the sink: o Energy resources: The energy resources is estimated by the number of packets, which the sensor node can send, if the sensor node has exclusive use of the path. o Additive QoS metric: A high additive QoS metric means low QoS.

The SAR algorithm selects the path based on the energy resources and additive QoS metric of each path, and the packet's priority level. As a result, each sensor node selects its path to route the data back to the sink. Also, two more algorithms called single winner election and multi winner election handle the necessary signaling and data transfer tasks in local cooperative information processing.

7.5.5 Low-energy Adaptive Clustering Hierarchy (LEACH)

LEACH [136] is a clustering-based protocol that minimizes energy dissipation in sensor networks. The purpose of LEACH is to randomly select sensor nodes as cluster-heads, so the high energy dissipation in communicating with the base station is spread to all sensor nodes in the sensor network. The operation of LEACH is separated into two phases, the set-up phase and the steady phase. The duration of the steady phase is longer than the duration of the set-up phase in order to minimize the overhead. During the set-up phase, a sensor node chooses a random number between 0 and 1. If this random number is less than the threshold T the sensor node is a cluster-head. After the cluster heads are selected, the cluster-heads advertise to all sensor nodes in the network that they are the new cluster-heads. Once the sensor nodes receive the advertisement, they determine the cluster that they want to belong based on the signal strength of the advertisement from the cluster-heads to the sensor nodes. The sensor nodes inform the appropriate cluster-heads that they will be a member of the cluster. Afterwards, the cluster-heads assign the time on which the sensor nodes can send data to the cluster-heads based on a TDMA approach. During the steady phase, the sensor nodes can begin sensing and transmitting data to the cluster heads. The cluster-heads also aggregate data from the nodes in their cluster before sending these data to the base station. After a certain period of time spent on the steady phase, the network goes into the set-up phase again and entering into another round of selecting the cluster-heads.

In [136] communication protocols, which can have significant impact on the overall energy dissipation of these networks are studied based on the findings that the conventional protocols of direct transmission, minimum-transmission-energy, multi hop routing, and static clustering may not be optimal for sensor networks, proposed LEACH (Low-Energy Adaptive Clustering Hierarchy), a clustering-based protocol that utilizes randomized rotation of local cluster base stations (cluster-heads) to evenly distribute the energy load among the sensors in the network.

LEACH [136] uses localized coordination to enable scalability and robustness for dynamic networks, and incorporates data fusion into the routing protocol to reduce the amount of information that must be transmitted to the base station. Simulations show that LEACH can achieve as much as a factor of 8 reduction in energy dissipation compared with conventional routing protocols. In addition, LEACH is able to distribute energy dissipation evenly throughout the sensors, doubling the useful system lifetime for the networks simulated.

7.5.6 Directed Diffusion

Directed diffusion [126, 131, 276] defines a data centric dissemination and co-ordination paradigm for delivering sensed data to the user. User queries or tasks are inserted as descriptive interest messages through a sink or entry node like Type = four footed animal, Interval = 20 ms Duration = 10s, Rectangle = [-100,100,200,400]. The interest query traverses from the sink node to the destination nodes using broadcast/multicast to the neighbors. During the traverse, gradients are created to keep track of delivering nodes with some identification of the interest message. Target nodes and neighbors co-operate to sense an object and the results traverse back to the sink following the gradients to the sink.

Diffusion, however is significantly lower-level, non-declarative interface and pays a considerable price in terms of usability and lacks latent for aggregate queries. However, in directed diffusion, limited data aggregation is performed on every node on the path from the source of the data to the source of the interest. Directed diffusion has the potential for significant energy efficiency; even with relatively un-optimized path selection it outperforms an idealized traditional data dissemination scheme like omniscient multicast. Directed diffusion can work against node failures by selecting new path and views the network as a data centric routing system (not as a database). This technique is totally centralized and uses limited caching and in-network processing.

In [126], localized algorithms, and directed diffusion, a simple communication model for describing localized algorithms is presented.

7.5.7 Rumor Routing

In [116] a scheme named rumor routing which allows event driven queries is presented. Rumor routing is designed for situations when geographic routing criteria are not applicable because a co-ordinate system is absent or the phenomenon of interest is not geographically correlated. "Rumor routing is tuneable and allows tradeoffs between setup overhead and delivery reliability".

7.5.8 RMST

In [164] directions and recommendations for implementing reliable data transport in sensor nets is presented guided by some analysis and experiments. RMST (Reliable Multi Segment Transport), a new transport layer for Directed Diffusion is provided to explore reliability at the transport layer. RMST provides guaranteed delivery and fragmentation/reassembly for applications that require them. RMST is a selective NACK-based protocol that can be configured for in-network caching and repair.

7.5.9 AFS

Bhatnagar et al. in [114], introduced the concept of service differentiation for sensor networks, highlighted its fundamental differences with normal data networks and define the relevant metrics. Various mechanisms which may provide services compatible with the packet priority levels are proposed. Adaptive Forwarding Scheme (AFS) is evaluated and found that the scheme provides the desired levels of service.

7.5.10 APS

Finding location without the aid of gps in each node is sometime important, location would also enable routing in sufficiently isotropic large network, without the use of large routing tables, aps [194] is a distributed hop by hop positioning algorithm that works as an extension of both distance vector and GPS and provides approximate location of all nodes in a network where a limited number of nodes have self location capability.

7.5.11 GPSR

In [147] Karp et al. presents Greedy Perimeter Stateless Routing (GPSR), a novel routing protocol for wireless datagram networks that uses the positions of routers and a packets destination to make packet forwarding decisions. GPSR makes greedy forwarding decisions using only information about a routers immediate neighbors in the network topology. When a packet reaches a region where greedy forwarding is impossible, the algorithm recovers by routing around the perimeter of the region. By keeping state only about the local topology, GPSR scales better in per-router state than shortest-path and ad-hoc routing protocols as the number of network destinations increases. Under mobilitys frequent topology changes, GPSR can use local topology information to find correct new routes quickly. Karp et al. in [147] describes the GPSR protocol, and use extensive simulation of mobile wireless networks to compare its performance with that of Dynamic Source Routing. The simulations demonstrate GPSRs scalability on densely deployed wireless networks.

In [160] a data-centric scalable, self-organizing, and energy-efficient data dissemination/routing approach is demonstrated. Ratnasamy et al. in [160] proposes a mechanism built upon the GPSR geographic routing algorithm and a new generation of efficient peer-to-peer lookup systems (such as Chord, CAN, Pastry, Tapestry, etc.)

7.5.12 CADR

Two novel techniques, information-driven sensor querying (IDSQ) and constrained anisotropic diffusion routing (CADR), for energy-efficient data querying and routing in ad hoc sensor networks for a range of collaborative signal processing tasks are described in [120]. The key idea is to introduce an information utility measure to select which sensors to query and to dynamically guide data routing. This allows to maximize information gain while minimizing detection latency and bandwidth consumption for tasks such as localization and tracking. simulation results have demonstrated that the information-driven querying and routing techniques are more energy efficient, have lower detection latency, and provide anytime algorithms to mitigate risks of link/node failures.

7.5.13 Ariadne

Prior research in ad hoc networking has generally studied the routing problem in a non-adversarial setting, assuming a trusted environment. However, in [139], Hu et al. presents attacks against routing in ad hoc networks, and the design and performance evaluation of a new secure on-demand ad hoc network routing protocol, called Ariadne. Ariadne prevents attackers or compromised nodes from tampering with uncompromised routes consisting of uncompromised nodes, and also prevents a large number of types of Denial-of-Service attacks. In addition, Ariadne is efficient, using only highly efficient symmetric cryptographic primitives.

7.5.14 GLS

GLS [151] is a new distributed location service which tracks mobile node locations. GLS combined with geographic forwarding allows the construction of ad hoc mobile networks that scale to a larger number of nodes than possible with previous work. GLS is decentralized and runs on the mobile nodes themselves, requiring no fixed infrastructure. Each mobile node periodically updates a small set of other nodes (its location servers) with its current location. A node sends its position updates to its location servers without knowing their actual identities, assisted by a predefined ordering of node identifiers and a predefined geographic hierarchy. Queries for a mobile nodes location also use the predefined identifier ordering and spatial hierarchy to find a location server for that node. Experiments using the ns simulator for up to 600 mobile nodes show that the storage and bandwidth requirements of GLS grow slowly with the size of the network. Furthermore, GLS tolerates node failures well: each failure has only a limited effect and query performance degrades gracefully as nodes fail and restart. The query performance of GLS is also relatively insensitive to node speeds. Simple geographic forwarding combined with GLS compares favorably with Dynamic Source Routing (DSR): in larger networks (over 200 nodes) GLS approach delivers more packets, but consumes fewer network resources.

7.5.15 GAF

A geographical adaptive fidelity (GAF) algorithm that reduces energy consumption in ad hoc wireless networks is introduced in [171]. GAF conserves energy by identifying nodes that are equivalent from a routing perspective and turning off unnecessary nodes, keeping a constant level of routing fidelity. GAF moderates this policy using application-and system-level information; nodes that source or sink data remain on and intermediate nodes monitor and balance energy use. GAF is independent of the underlying ad hoc routing protocol; here simulated GAF over unmodified AODV and DSR. Analysis and simulation studies of GAF show that it can consume 40% to 60% less energy than an unmodified ad hoc routing protocol. Moreover, simulations of GAF suggest that network lifetime increases proportionally to node density; in one example, a four-fold increase in node density leads to network lifetime increase for 3 to 6 times (depending on the mobility pattern). More generally, GAF is an example of adaptive fidelity, a technique proposed for extending the lifetime of self-configuring systems by exploiting redundancy to conserve energy while maintaining application fidelity.

7.5.16 Based on AODV and DSR

In [171, 172] Xu et al. presents two algorithms for routing in energy-constrained, ad hoc, wireless networks. Nodes running these algorithms can trade off energy dissipation and data delivery quality according to application requirements. the algorithms work above existing on-demand ad hoc routing protocols, such as AODV and DSR, without modification to the underlying routing protocols. Major contributions are: algorithms that turn off the radio to reduce energy consumption with the involvement of application-level information, and the additional use of node deployment density to adaptively adjust routing fidelity to extend network lifetime. Algorithm analysis and simulation studies show that this energy conserving algorithm can consume as little as 50% of the energy of an unmodified adhoc routing protocol. Moreover simulation of adaptive fidelity shows that greater node density can be used to increase network lifetime. In an example four fold increase in density doubled network lifetime [172].

in [117] Broach et al. presents the results of a detailed packet-level simulation comparing four multi-hop wireless ad hoc network routing protocols that cover a range of design choices: DSDV, TORA, DSR, and AODV. [117] has extended the ns-2 network simulator to accurately model the MAC and physical-layer behavior of the IEEE 802.11 wireless LAN standard, including a realistic wireless transmission channel model, and presented the results of simulations of networks of 50 mobile nodes.

7.5.17 GEAR

Design and evaluation of an energy efficient routing algorithm that propagates a query to the appropriate geographical region, without flooding are provided in [177]. The proposed Geographic and Energy Aware Routing (GEAR) algorithm uses energy aware neighbor selection to route a packet towards the target region and Recursive Geographic Forwarding or Restricted Flooding algorithm to disseminate the packet inside the destination region.

Simulation of GEAR show that, especially for non-uniform traffic distribution, GEAR exhibits noticeably longer network lifetime than non-energy-aware geographic routing algorithms.

7.5.18 Multi-path Routing

In [127], Ganesan et al. proposes the use of multi-path routing to increase resilience to node failures. Multi-path routing techniques have been discussed in the literature for several years. However, the application of multi-path routing to sensor networks and other systems that permit data-centric routing with localized path setup has not yet been explored. Two different approaches to constructing multi-paths between two nodes are considered. One is the classical node-disjoint multi-path adopted by prior work, where the alternate paths do not intersect the original path (or each other). The disjoint property ensures that, when alternate paths are constructed, no set of node failures can eliminate all the paths. The other approach abandons the requirement for disjoint paths and instead builds many braided paths. With braided paths, there are typically no completely disjoint paths but rather many partially disjoint alternate paths.

In [127] Ganesan et al. mainly addresses two issues. First, defining localized algorithms for the construction of alternate paths. While it is straightforward to define idealized notions of disjoint and braided paths, these definitions do not lend themselves to scalable implementation. For reasons of robustness and energy-efficiency, sensor networks data dissemination mechanisms use localized decisions for path setup and for recovery from failure. It proposed localized algorithms to compute approximations to the idealized disjoint and braided paths.

Second, the relative performance of disjoint and braided multi-paths is studied. Two important metrics in judging the performance of these competing approaches were used. The resilience of a scheme measures the likelihood that, when the shortest path has fails, an alternate path is available between source and sink. The maintenance overhead of a scheme is a measure of the energy required to maintain these alternate paths using periodic keep alives. There is an inherent tradeoff between these two quantities. Becoming more resilient typically consumes more energy. this paper investigates the tradeoffs that result from the two proposed routing algorithms.

7.5.19 Ant Algorithms

Ant Algorithms [166] are a class of agent based routing algorithms modelled after ant behavior. Agents traverse the network encoding the quality of the path they have travelled, and leave it the encoded path as state in the nodes. At every node, an agent picks its next hop probabilistically, but biased toward already known good paths. This results in faster and more thorough exploration of good regions, and a path for queries to follow [122]. These algorithms are very effective in dealing with failure, since there is always some amount of exploration, especially around previously good solutions. However, due to the large number of nodes, the number of ant agents required to achieve good results tends to be very large, making them difficult to apply in sensor networks.

7.5.20 Other Works

Sensor networks differ from traditional networks in several ways: sensor networks have severe energy constraints, redundant low-rate data, and many-to-one flows. The end-to-end routing schemes that have been proposed in the literature for mobile ad-hoc networks are not appropriate under these settings. Data-centric technologies are needed that perform in-network aggregation of data to yield energy-efficient dissemination.

Wicker et al. in [169] model data-centric routing and compare its performance with traditional end-to-end routing schemes. It examines the impact of source-destination placement and communication network density on the energy costs, delay, and robustness of data aggregation. It is found that that data-centric routing offers significant performance gains across a wide range of operational scenarios.

Lindsey et al. in [153] presents the problem of data collection from a sensor web, where nodes have packets of data in each round of communication that need to be gathered and fused with other node's packets into one packet and transmitted to a distant base station. Nodes have power control in their wireless communications and can transmit directly to any node in the network or to the base station. With unit delay cost for each packet transmission, if all nodes transmit data directly to the base station, then both high energy and high delay per round will occur.

Ganesan et al. in [129] investigates design tradeoffs relating to the structure of the network formed in large-scale self-organizing wireless sensor systems. Flooding, which is conventionally used for disseminating information, can also be used for network discovery. here It is of interest to know whether the discovered routing tree is bushy, with a few large clusters, or sparse, with many smaller clusters. Three factors affecting the structure of the discovered routing tree are the flooding mechanism, the transmission power, and the parent selection algorithm. The bushiness of the discovered tree structure will have direct implications in terms of application data aggregation, energy utilization, system throughput and robustness. a number of related questions and tradeoffs among these implications are answered.

The first description of the software architecture that supports named data and in-network processing in an operational, multi-application sensor-network is proposed in [253]. It shows that approaches such as in-network aggregation and nested queries can significantly affect network traffic. In one experiment aggregation reduces traffic by up to 42% and nested queries reduce loss rates by 30%. Although aggregation has been previously studied in simulation. In [253] Heidemann et al. also demonstrates nested queries as another form of in-network processing, and it presents the first evaluation of these approaches over an operational test bed.

Royer et al. in [161] examines a set of routing protocols and evaluates these protocols based on a given set of parameters. the article provides an overview of eight different routing protocols by presenting their characteristics and functionality and then provides a comparison and discussion of their respective merits and drawbacks.

Intanagonwiwat et al. in [140], proposes a greedy approach for constructing a greedy aggregation tree to improve path sharing. It evaluates the performance of this greedy approach by comparing it to the prior opportunistic approach. preliminary result suggests that although the greedy aggregation and the opportunistic aggregation are roughly equivalent at low-density networks, the greedy aggregation can achieve significant energy savings at higher densities. In one experiment it is found that the greedy aggregation can achieve up to 45% energy savings over the opportunistic aggregation without an adverse impact on latency or robustness.

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8 Location Mechanism/Deployment/Target Tracking

A beacon placement specially affects spatial localization, a critical service for context awareness application. Fixed beacon placement such as uniform and very dense placement is not always applicable or adequate for a very noisy environment. The paper motivates the need for empirically adaptive beacon placement [181]. It also outlines a general approach of beacon placement based on exploration and instrumentation of the terrain conditions by a mobile human or robotic agent. The beacon placement algorithm is applicable to low(beacon) density regime of operation.noise makes moderate density regimes more improvable [181].

In [186] Clouqueur et al. address the deployment problem by proposing path exposure as a measure of the goodness of a deployment and presents an approach for sequential deployment in steps. It illustrates that the cost of deployment can be minimized to achieve the desired detection performance by appropriately choosing the number of sensors deployed in each step [186]. This paper also investigates deployment strategies for sensor networks performing target detection over a region of interest. In order to detect a target moving through the region, sensors have to make local observations of the environment and collaborate to produce a global decision that reflects the status of the region covered. This collaboration requires local processing of the observations, communication between different nodes, and information fusion Since the local observations made by the sensors depend on their position, the performance of the detection algorithm is a function of the deployment. One possible measure of the goodness of deployment for target detection is called path exposure. It is a measure of the likelihood of detecting a target traversing the region using a given path. The higher the path exposure, the better the deployment. The set of paths to be considered may be constrained by the environment [186]. The focus of this paper is to determine the number of sensors to be deployed to carry out target detection in a region of interest. The tradeoffs lie between the network performance, the cost of the sensors deployed, and the cost of deploying the sensors. The problem of random deployment is formulated and several solutions are presented [186].

An algorithm for tracking multiple target in a cluttered environment is developed [196]. The strategy is capable of initiating tracks, accounting for false or missing reports and processing sets of dependent reports, as each measurement is received probabilities are calculated for the hypothesis, that the measurement came from previously known targets in a target file or from a new target or that the measurement is false [196]. A scalable object tracking through unattended techniques is provided in [187]. Maximum Likelihood Source Localization and Unknown Sensor Location Estimation for Wideband Signals in the Near Field was used [187].

Location support system traditionally tradeoff positional accuracy, uncertainty and latency in providing location information for easy of configuration, lower hardware costs, energy efficiency,scalability or preserving user privacy. we explore these tradeoffs by discussing the design space of location support system and their impact on applications [179]. Applications informed of these tradeoffs can adapt to them and substantially improve the performance. So here Locations models are described those are be quality expressive i.e. provide an explicit representation of parameters such as accuracy, timeliness, energy costs of location information [179]. The motivation, design, implementation and evaluation of a self-configuring localization system based on beacons is proposed [182]. To address beacon deployment issues, in [182] Bulusu et al. introduced the novel concept of self-configuring beacon networks. It also identified density as an important parameter in characterizing localization quality, developed a methodology and propose two algorithms for system self-configuration based on beacon density. For sparse and medium density deployments, it proposed the HEAP algorithm to detect regions with poor localization, and select candidate points for placing new beacons. For dense beacon deployments, it proposed the STROBE algorithm. STROBE enables densely deployed beacons to coordinate without self-interference and opportunistically conserve energy [182]. The paper also evaluated and demonstrated the effectiveness of the solutions. It used simulations to explore in detail the implications of several design choices. It presents the measured performance of an implementation of a radio based localization system that demonstrates that the granularity of localization improves by adding beacons at points selected by the HEAP algorithm. It also verify and validate the simulated performance of the STROBE algorithm using experimental emulations [182]. A taxonomy is developed to help developers of location-aware applications better evaluate their options when choosing a location-sensing system. The taxonomy may also aid researchers in identifying opportunities for new location-sensing techniques [191]. in [184]first described the physical features of the sources and their propagation properties and discuss the system features of the sensor network then introduces some early works in source localization, DOA estimation, and beamforming. Other topics discussed include the closed-form least-squares source localization problem, iterative ML source localization, and DOA estimation [184].

A novel approach to the localization of sensors in an ad-hoc network is presented in [198]. It describes a system called AHLoS (Ad-Hoc Localization System) that enables sensor nodes to discover their locations using a set of distributed iterative algorithms. The operation of AHLoS is demonstrated with an accuracy of a few centimeters using a prototype test bed while scalability and performance are studied through simulation [198]. A review of localization techniques and evaluation of the effectiveness of a very simple connectivity-metric method for localization in outdoor environments that makes use of the inherent radio-frequency (RF) communications capabilities of these devices is done [180]. A fixed number of reference points in the network with overlapping regions of coverage transmit periodic beacon signals is considered [180].

Finding location without the aid of GPS in each node is sometime important, location would also enable routing in sufficiently isotropic large network,without the use of large routing tables, aps a distributed hop by hop positioning algorithm that works as an extension of both distance vector and GPS IN order to provide approximate location of all nodes in a network where a limited number of nodes have self location capability is described [194, 197] proposes a set of algorithms called sniffers for the problem of locating a target object moving through a geographic area using an adhoc sensor network. it is an application level solution and works with memory and energy limitations.sniffer conserves energy by efficiently identifying the node that sighted for the target object and then using local messages between neighboring nodes to follow the trail of the object. it lessens message transfer but increases time [15, 197] Developed and implemented a complete proximity detector in order to give a wearable computer such as PDA location context.

The development of a system, based on commercial off-the-shelf (COTS) components is discussed in [190], which is capable of automatic localization and time synchronization with sufficient precision (on the order of 10cm and sec) to support distributed, coherent signal processing. the system's time synchronization is an implementation of Reference-Broadcast Synchronization (RBS), Localization is based on an underlying ranging system that works by timing the flight of a wide band acoustic pulse [190].

A new randomized algorithm is proposed for maintaining a set of clusters among moving nodes in the plane, Such a kinetic clustering can be used in numerous applications where mobile devices must be interconnected into an ad-hoc network to collaboratively perform some task [189]. A method for estimating unknown node positions in a sensor network based exclusively on connectivity-induced constraints is described [188]. Known peer-to-peer communication in the network is modelled as a set of geometric constraints on the node positions. The global solution of a feasibility problem for these constraints yields estimates for the unknown positions of the nodes in the network. Providing that the constraints are tight enough, simulation illustrates that this estimate becomes close to the actual node positions [188]. Additionally, a method for placing rectangular bounds around the possible positions for all unknown nodes in the network is given. The area of the bounding rectangles decreases as additional or tighter constraints are included in the problem. Specific models are suggested and simulated for isotropic and directional communication, representative of broadcast-based and optical transmission respectively, though the methods presented are not limited to these simple cases [188].

Three themes are explored [178] in the design of self-configuring sensor networks: tuning density to trade operational quality against lifetime; using multiple sensor modalities to obtain robust measurements; and exploiting fixed environmental characteristics. It is also illustrated these themes through the problem of localization [178]. In this paper, it is explored the coordination in wireless sensor networks based on adaptive localized algorithms that exploit both the local processing available at each node as well as the redundancy available in densely distributed sensor networks. An introduce of the design themes of density, multiple sensor modalities and adaptation to fixed environments, and show how they can be applied to build self-configuring localization systems is done [178].

One of the fundamental problems, namely coverage is addressed in the paper [193]. Coverage in general, answers the questions about quality of service (surveillance) that can be provided by a particular sensor network. It first defines the coverage problem from several points of view including deterministic, statistical, worst and best case, and present examples in each domain. By combining computational geometry and graph theoretic techniques, specifically the Voronoi diagram and graph search algorithms, it establishes the main highlight of the paper - optimal polynomial time worst and average case algorithm for coverage calculation [193]. A comprehensive experimental results is presented and a discussion of future research directions is provided related to coverage in sensor networks [193]. It also studies asymptotic coverage behavior of random wireless ad-hoc networks [193].

A description, validation and evaluation in real environments a very simple self localization methodology for RF-based devices based only on RF connectivity constraints to a set of beacons (known nodes), applicable outdoors is presented. Beacon placement has a significant impact on the localization quality in these systems. To self-configure and adapt the localization in noisy environments with unpredictable radio propagation vagaries, it introduces the novel concept of adaptive beacon placement [183]. It also proposes several novel and density adaptive algorithms for beacon placement and demonstrate their effectiveness through evaluations [183]. It also outlines an approach in which beacons leverage a software controllable variable transmit power capability to further improve localization granularity. These combined features allow a localization system that is scalable and ad hoc deployable, long-lived and robust to noisy environments. The unique aspect of the localization approach is the emphasis on adaptive self configuration [183].

The design, implementation, and evaluation of Cricket, a location-support system for in-building, mobile, location dependent applications is proposed [195]. It allows applications running on mobile and static nodes to learn their physical location by using listeners that hear and analyze information from beacons spread throughout the building [195].

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9 Distributed Network:Topology Discovery

Issues related to topology maintenance in Adhoc Wireless Networks is discussed [208]. The topology that best supports communication among these sensor nodes is presented in [210]. It proposes a power-aware routing protocol and simulate the performance, showing that the discussed routing protocol adapts routes to the available power. This leads to a reduction in the total power used as well as more even power usage across nodes. We consider different routes and topologies, demonstrating the difference in performance and explaining the underlying causes [210]. Two topology control protocols that extend the lifetime of dense ad hoc networks while preserving connectivity, the ability for nodes to reach each other are presented [211]. The protocols conserve energy by identifying redundant nodes and turning their radios off [211].

A topology discovery algorithm (TopDisc) for wireless sensor networks with its applications to network management is described [209]. Nodes will have to self-configure to establish a topology that provides communication and sensing coverage under stringent energy constraints. In [207] Cerpa et al. state that each node assesses its connectivity and adapts its participation in the multi-hop network topology based on the measured operating region. The paper motivates and describes the adaptive self configuring algorithm and presents simulation and experimental measurements [207].

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10 Distributed Network: Time Synchronization

Time synchronization is critical in sensor networks for diverse purposes including sensor data fusion, coordinated actuation, and power-efficient duty cycling. Though the clock accuracy and precision requirements are often stricter than in traditional distributed systems, strict energy constraints limit the resources available to meet these goals.

Reference-Broadcast Synchronization, a scheme in which nodes send reference beacons to their neighbors using physical-layer broadcasts is presented [213]. A reference broadcast does not contain an explicit timestamp; instead, receivers use its arrival time as a point of reference for comparing their clocks [213]. It uses measurements from two wireless implementations to show that removing the sender's nondeterminism from the critical path in this way produces high-precision clock agreement (1.85 1.28sec, using off-the-shelf 802.11 wireless Ethernet), while using minimal energy. It also describes a novel algorithm that uses this same broad cast property to federate clocks across broadcast domains with a slow decay in precision (3.68 2.57sec after 4 hops). RBS can be used without external references, forming a precise relative timescale, or can main- tain microsecond-level synchronization to an external timescale such as UTC. It shows a significant improvement over the Network Time Protocol (NTP) under similar conditions [213].

Describes an implementation of an adhoc distributed sensor platform that provides synchronized time to its users using RBS [214]. In [215] Elson and Estrin argue that time synchronization schemes developed for traditional networks such as NTP are ill-suited for WSNs and suggest more appropriate approaches [215]. The synchronization requirements of future sensor networks is outlined and an implementation of the low power synchronization scheme is presented that is a post facto synchronization [212]. The paper also describes an experiment that characterizes its performance for creating short-lived and localized but high precision synchronization using very little energy [212]. The solution provided by [216] centers around the development of a deterministic time synchronization method relevant for wireless sensor networks. The proposed solution features minimal complexity in network bandwidth, storage and processing and can achieve good accuracy. It is highly relevant for sensor networks, it also provides tight, deterministic bounds on both the offsets and clock drifts [216]. Here a method to synchronize the entire network in preparation for data fusion is presented. A real implementation of a wireless ad-hoc network is used to evaluate the performance of the proposed approach [216].

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11 Miscellaneous topics on Network Layer

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12 Application Layer

In [240] Schwiebert et al. describe the novel approach to providing a complete system for restoring vision to visually impaired persons - from the signals generated by an external camera to an array of sensors that electrically stimulate the retina via a wireless interface. In [231] Bonnet et al. present a concrete example of an existing flood detection system. For about twenty years now, the ALERT system has been deployed in several US states (http://www.alertsystems.org). A typical ALERT installation consists of several types of sensors in the field: rainfall sensors, water level sensors, weather sensors and so on. [231]. The process of monitoring the status of a sensor network and figuring out the problematic sensor nodes sensor network diagnosis is defined [254]. However, the high sensor node-to-manager ratio makes it extremely difficult to pay special attention to any individual node [254].

A brief description of Habitat monitoring application is provided in [232] and introduces initial system building blocks designed to support this application. To address this, here proposed a tiered system architecture in which data collected at numerous, inexpensive sensor nodes is filtered by local processing on its way through to larger, more capable and more expensive nodes [232]. A description of the potentials of bio medical smart sensors is provided in [241], it also explains the challenges for wireless networking of human embedded smart sensor arrays, describes wireless networking of retina prosthesis [241]. Here examined the emerging field to classify wireless micro-sensor networks according to different communication functions, data delivery models and network dynamics. This taxonomy will aid in defining appropriate communication infrastructures for different sensor network application sub-spaces, allowing network designers to choose the protocol architecture that best matches the goals of their application [243].

An investigation of task-decomposition and collaboration in a two-tiered sensor network for habitat monitoring is done [245]. The system has a few powerful macro nodes in the first tier, and many less-powerful micro nodes in the second tier [245]. The application of sensor-based wireless networks to a Smart Kindergarten that are developed to target developmental problem-solving environments for early childhood education is provided and studied [242]. In-depth study is provide to apply wireless sensor networks to real-world habitat monitoring. A set of system design requirements are developed that cover the hardware design of the nodes, the design of the sensor network, and the capabilities for remote data access and management. A system architecture is proposed to address these requirements for habitat monitoring in general, and an instance of the architecture for monitoring seabird nesting environment and behavior is presented [237].

An investigation of two hierarchical, self-configuring or unattended approaches for an efficient object location service is provided [235]. The first approach, SCOUT-AGG, is based on aggregation of object names. The second approach, SCOUT-MAP, is based on indirection, where information about an object is stored at the locator sensor for the object [235]. In [244] an acoustic habitat-monitoring sensor network is developed that recognizes and locates specific animal calls in real time. The paper investigates the system requirements of such a real-time acoustic monitoring network. It proposes a system architecture and a set of lightweight collaborative signal processing algorithms that achieve real-time behavior while minimizing inter-node communication to extend the system lifetime. In particular, the target classification is based on spectrogram pattern matching while the target localization is based on beam forming using Time Difference Of Arrival (TDOA) [244]. For acoustic acquisition and processing, plus external wireless Ethernet cards for radio communication to form a distributed sensor network to perform acoustical beamforming is proposed [239, 246] outlines how the application can be exploited in the network design to enable sustained low-power operation. In particular, extensive information processing at nodes, hierarchical decision making, and energy conserving routing and network topology management methods are employed in the networks under development.

Security Protocols for Sensor Networks are described in [238]

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13 Operating System/Software

An appropriate operating system is needed for the proper functionality of sensor network. As sensors are very small devices the code for the operating system should be very small also using very limited resources like storage, ram, power etc. but as sensors work in realtime environment they should process data in real time also for efficiency purposes they should support parallel processing along with threading when a sensor is deployed for multiple purposes. To become sensor networks most useful this area needs special research.

Operating System Design, Requirement Analysis is done in [247, 248, 249, 252, 253]. An OS requirement study is provided in [248]. In [249] Dulman et al. consider limited amount of resources to operating system design. Some important and extensive design issues of sensor networks are discussed in [256]. The issues addressed are example design points such as hardware organization, power characteristics, and tiny micro-threading OS issues such as OS design, OS components, OS components type, Effect of putting components together. Besides, sensor characteristics and evaluation and architectural implications of sensor characteristics are explained [256]. Operating system design with modularity and concurrent intensive computation support [248, 252], design considering low resources [248, 253] are also provided. Concurrent, parallel processing issues are covered in [253, 256].

A new packet scheduling policy supporting realtime application is presented [255]. Also some strategies to handle real time data of sensor networks is provided [257]. A system simulator for the basement distributed real-time system is provided [252]. An Off-Line Scheduler for sensor networks is provided [252]. Some scheduling strategies for sensor networks are provided [251].

A network centric approach to designing software for highly constrained devices having tinyos, active message communication models,and its use to create non blocking applications and higher level network capabilities(multihop,adhoc routing) are explained in [248]. A programming language, Multilevel Human Machine Interface to create real time softwares for sensor networks are provided [250]. Software architecture that supports named data and in network processing in an operational, multi application sensor network, nested queries in network processing, naming scheme, and how this scheme facilitates application specific in network processing(localized data aggregation) are provided [253]. An approach for programming event driven embedded system, maintaining concurrency is provided [247]. [247] also uses the features to generate an application specific operating system for thread safe execution [247].

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14 Sensor Network Simulation

Sensorsim, a simulation framework that introduces new models and techniques for the design and analysis of sensor networks is developed [259]. Sensorsim inherits the core features of traditional event driven network simulators as well as builds up new features that include ability to model power usage in sensor nodes [259]. Sensorsim supports hybrid simulation that allows the interaction between real and simulated nodes, new communication protocols and real time user interaction with graphical data display [259].

Existing tools for modelling wireless networks focus only on communication problems, do not support modelling power and sensing aspects. [260] presents a set of models and techniques that are embodied in a simulation tool for modelling wireless sensor networks. This models are derived with detail power measurements involving two different types of sensor nodes high end WINS nodes by Rockwell and low end experimental nodes built by the authors [260].

A Description of trade offs associated with adding detail to simulation models is provided [258]. Effects of detail in five case studies of wireless simulations for protocol design is evaluated. Ultimately the researcher must judge which level is required for a given question. However, here two approach is suggested to cope with varying levels of details. When error is not correlated, networking algorithms that are robust to a range of errors are often stressed in similar ways by random error as by detailed models. It suggests visualization techniques that can help pinpoint incorrect details and manage detail overload [258].

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15 Querying Sensor Network

Advances in hardware for sensor nodes that combine sensors, embedded processors, and communication components have made the large-scale deployment of sensor networks a reality. Various sensor network applications ranging from monitoring to military applications require sensor nodes to collect data over a continuous time period. For the placement, management, and processing of the sensor data, a data storage, management and query processing policy is necessary. In this paper, we attempt to identify the key query processing techniques used in sensor networks, evaluate them in terms of efficiency, scalability, and applicability and outline the most challenging research directions. We start by identifying a set of design goals and challenges related to query processing over sensor networks. The evaluation of the techniques is guided by the distinctive query processing features supported by both conventional and wide area sensor networks.

Recent advancements in technology have enabled the widespread deployment of sensor networks consisting of a large number of sensor nodes with sensing, computation, and communication capabilities. Sensor networks aim at providing an efficient and effective bridge between physical and computational worlds. Typical sensor network applications show a great deal of diversity including contaminant transport monitoring, marine microorganisms analysis, habitat sensing, seismic and home monitoring, and more. From small, low powered, and wireless sensors to webcams, microphones, and pressure gauges, pervasive sensors provide excellent new services for these applications. Querying and monitoring the physical world is one these services bearing utmost importance. Consider for example a Trip Planner service used for finding out the current traffic condition of streets leading to a users destination. The user enters into a PDA (or a car navigation system) his origin and destination and gets back information regarding the traffic condition of every possible street that leads to the destination. A threefold requirement is envisioned to create such a Trip Planner service. First, sensors are located in different locations on the street and can determine the current traffic rate. Second, a sensor database is needed that can store dynamic information such as the current traffic rate and the speed of vehicles along with some static information such as possible ways to reach the destination. Third, a web accessible query processing system is needed to provide replies to high-level user queries.

Unfortunately, the resource constraints related to sensor nodes such as computation, communication, power consumption, uncertainty in sensor readings have posed a numerous challenges in query processing for sensor networks. Therefore, research on efficient query processing for sensor networks has become an important activity. To this end, databases in sensor networks are recently attaining a great attention of researchers.

So far, reasonable work has been done on different query processing techniques in the context of both conventional and wide area sensor networks. Conventional sensor networks consist of very small, power-constrained, wireless sensors having very simple processors, little memory and limited sensing capabilities. The Directed diffusion [275], the Cougar approach [264, 290, 291], the TAG [281], the Fjords [280] and some other techniques have been devised for querying the conventional networks. These query processing techniques operate directly on continuous and never-ending streams of sensor data and take special care on using low power as the sensor nodes are power-constrained. Besides, wide area sensor networks can have both tiny and large (powered and high-bit-rate) sensors [273] spread over a wide geographically dispersed region. Databases used by these networks are also dispersed and contain data that correspond to the most recent updates by the sensors. Unfortunately, little research has been conducted on wide area sensor databases. The IrisNet (Internet-scale Resource-intensive Sensor Network Services) project works with wide area sensor databases and develops a novel query processing technique that is applicable to hierarchical distributed databases created by any wide area sensor network.

Our overall strategic goal is to identify the key features adopted by current query processing techniques for sensor networks, evaluate them in terms of efficiency, scalability, applicability, and reliability and to outline the most challenging future research directions for the development of new techniques. We envision providing emphasis on: Identifying the requirements and challenges for sensor networks queries: The requirements for query processing may vary depending on the types of sensor networks and the applications being deployed. Nevertheless, a number of common requirements are shared among all sensor network applications regardless of the usage such as a simple query language, aggregation of query data, less query response time, and multi query management. At the same time, sensor networks pose a number of query processing challenges due to the resource constrained sensor nodes (low power, small size, and less storage) and the nature of sensor data. Identifying the interoperability and integration issues: Query processing techniques should be compatible to both conventional and wide area sensor networks. Besides, integration of conventional and wide area sensor databases should be supported to provide a common query language interface. Optimum design: The first tendency could be to optimize each and every component to the maximal extent. Identifying the area where to put the main optimization effort is important. For example, supporting more in-node aggregation operations, filtering sensor data, and supporting the usage of intermediate result for different queries could be important design issues. Identifying trade-offs due to resource constraint: A number of possible trade-offs should be considered depending on the sensor node resources. For example, increasing node computation to minimize the amount of communication in order for the power consumption to be kept a minimum could be a design goal where the underlying network architecture supports sufficient local storage.

The remainder of the paper is organized as follows. Section 2 outlines important query processing challenges. Section 3 then presents different query processing techniques and evaluates them. Next, section 4 provides the challenging research directions for the development of new querying techniques. Finally, the paper ends with conclusions in section 5.

15.1 Query processing challenges

In this section, an overview of research problems for query processing in sensor networks is presented in the context of both conventional and wide area sensor networks.

15.1.1 Conventional Sensor Network Databases

Streaming Data: In traditional database systems, data is static and the query processor pulls data from the disk, orchestrate the movement and handling of data but sensor networks involve streaming data where data is continuously pushed to the query processor, which must react to the arriving data. The data arrival rate may be extremely high or bursty, thus placing constraints on processing time or memory usage. Data must be processed dynamically as it arrives and can be spooled to the disk in background mode. Also, in many data streams, time and ordering of data are inherently important.

Continuous Queries: Monitoring applications are common sensor applications where queries remain continuously active. When new data comes or an event happens, data are supplied to the stored and continuously active queries whereas in a traditional system, the arrival of queries initiates access to a stored collection of data. The streams pushed to continuous queries can be effectively infinite leading the query processors to include different query semantics, non-blocking query operators, and tolerance of failure. Continuous queries can be extremely long lived, which makes them susceptible to changes over time in performance and load, data arrival rates, or data characteristics.

Resource constrained sensor nodes: Sensor nodes are resource-constrained having very low power, limited memory, very simple processors, and limited sensing capabilities. Besides, wireless communications consume much battery power. Therefore, the query processor should be designed so as to overcome these limitations.

Aggregation: Aggregation refers to collecting, filtering, and processing sensor data in the network, and supplying the result to the central nodes. Aggregation reduces wireless communication and hereby minimizes power usage. Hence, an efficient aggregation plan is needed considering the volatility of the underlying data.

Query Languages: Technological development is leading to various sensor based applications driving diverse requirements for the query language. Hence, the development of a user friendly, efficient, generalized query language is at a difficult point.

Query Optimization: A complex query may consist of a large number of parameters and operators, in addition to various user requirements on the query answers. There is usually a large space of query processing plans for such complex queries, and it is the query optimizer's responsibility to select a good plan within a large space of possible query execution plans.

Catalog Management: To generate a good plan for the user query, the query optimizer needs to know the current status of the network to evaluate the costs and benefits of different query plans. Multi Query Optimization: Simultaneous multiple query support and optimization is another challenging issue.

15.1.2 Wide Area Sensor Network Databases

Data Partitioning and Placement: Physical placement and keeping track of sensor data is an important issue due to the huge volume of data and multiple and geographically dispersed databases. The data is partitioned in such a way that Query processor can find appropriate site for providing results within a short period. Caching: An efficient caching strategy can help a lot. If data is cached depending on the query and application in different sites they can provide dramatic decrease in query response time. Query processing and query language: The query language should support diverse applications and at the same time should be efficient and user friendly. The query processing technique should be able to handle a large number of sensors, diverse queries, multiple concurrent queries, and large volumes of data.

15.2 Different query processing techniques

This section presents different query processing techniques for both conventional and wide area sensor networks with their relative advantages and limitations.

15.2.1 Conventional Sensor Networks

- **Directed Diffusion**

  Directed diffusion defines a data centric dissemination and co-ordination paradigm for delivering sensed data to the user. User queries or tasks are inserted as descriptive interest messages through a sink or entry node like Type = four footed animal, Interval = 20 ms Duration = 10s, Rectangle = [-100,100,200,400]. The interest query traverses from the sink node to the destination nodes using broadcast/multicast to the neighbors. During the traverse, gradients are created to keep track of delivering nodes with some identification of the interest message. Target nodes and neighbors co-operate to sense an object and the results traverse back to the sink following the gradients to the sink [275].

Diffusion, however is significantly lower-level, non-declarative interface and pays a considerable price in terms of usability and lacks latent for aggregate queries. However, in directed diffusion, limited data aggregation is performed on every node on the path from the source of the data to the source of the interest. Directed diffusion has the potential for significant energy efficiency; even with relatively un-optimized path selection it outperforms an idealized traditional data dissemination scheme like omniscient multicast. Directed diffusion can work against node failures by selecting new path and views the network as a data centric routing system (not as a database). This technique is totally centralized and uses limited caching and in-network processing.

- **Cougar Approach**

Cougar approach mainly focuses on in-network distributed query processing. In case of centralized traditional sensor networks, sensors are preprogrammed, and always send data to the central node for offline querying and processing. In addition, the network and the applications are static. Users cannot change the system behavior on the fly. Besides, there is huge consumption of battery power due to wireless communications [264, 290, 291].

Cougar approach solves these problems to a great extent. The main idea of cougar approach is in- network data processing. The sensors are capable of storing some data and perform processing like aggregating records or eliminating irrelevant records and send only the necessary data to the base station. Besides, a declarative, user friendly query language is developed. Hence, users are shielded from the internal structure of sensor networks. A query optimizer at the base station depending on the user query generates an efficient query plans for in-network query processing. An efficient query proxy layer in each sensor node is designed that resides between the network and the application layer. The query plan specifies data flow routes and exact computation plan such as which node will perform the computation.

The plan is then delivered to all the related sensors of this plan. Also, control structures are needed to synchronize sensor behavior. Query optimizer assigns a leader for a group of sensors who will collect data and send data to the leader. Leader nodes perform computations while non-leader nodes have a scan operator to read sensor values periodically and to send them to the leader node. In addition, their plan contains an aggregation operator to aggregate data from other sensors. In essence, Cougar approach introduces aggregation, in-network-query processing, query proxy layer, a declarative query language in attention to using less battery-power.

- **Acquisitional query processing (ACQP)**

  ACQP works in the setting where the data to be processed does not exist at the sites when the query is issued but generates data actively by acquiring samples from special sensing devices. ACQP uses a set of techniques for deciding when and where to sample and which data to deliver with the combination of in-network aggregate processing like cougar approach. Based on these concepts, TinyDB, a DBMS for sensor networks is built. Unlike existing solutions for data processing, TinyDB does not require to write embedded C code for sensors. Instead, like traditional databases, TinyDB provides a simple, SQL-like interface to specify the query, along with additional parameters such as the rate at which data should be refreshed. Given a user query, TinyDB collects data from motes in the environment, filters it, aggregates it together, and routes to a PC. TinyDB does this using power-efficient in-network processing algorithms [279, 282].

- **Fjords Architecture**

  The Fjords architecture [280] manages multiple queries over many sensors, and reduces sensor resource demands but provides high query throughput. The architecture addresses the low level infrastructure problem in a sensor stream query processor using two techniques. First, it combines proxies, non-blocking operators, and conventional query plans. Second, sensor proxies serve as a bridge between sensors and query plans, using sensors to facilitate query processing while being sensitive to their power, processor, and communications limitations. The Fjords architecture provides support for integrating streaming data that is pushed into the system with disk-based data, which is pulled by traditional operators. Fjords allow combining multiple queries into a single plan and explicitly handle operators with multiple inputs and outputs. Previous database architectures are not capable of combining streaming and static data. The hybrid approach adopted by Fjords is an essential part of any data processing system which claims to be able to compute over streams. These solutions are an important part of the Telegraph Query Processing System [285], which seeks to extend traditional query processing capabilities to a variety of nontraditional data sources. Telegraph when enhanced with the Fjords sensor stream processing techniques, enables query processing over networks of wireless, battery powered devices that cannot be queried through traditional means.

- **Continuous queries**

Recently, there have been a lot of interests in streaming data and continuous query processing. TelegraphCQ [267] is a recent project to handle continuous queries which focuses on the extreme adaptability and it has the required novel infrastructure. NiagaraCQ [268], an XML-based engine builds static plans for the different continuous queries in the systems, and allows two queries to share a module if they have the same input. Babu and Widom [262] deal with STREAM, which focuses on computing approximate results, analyzing the memory requirements of posed queries and running queries in a bounded amount of memory. The Aurora [266] system works with quality-of-service for queries to meet the need for heterogeneous user requirements. Gehrke et al. [272] consider the problem of computing correlated aggregate queries over streams, and presents techniques for obtaining approximate answers in a single pass. Yang et al. [11] discuss data structures for computing and maintaining aggregates over streams to support fast lookup of aggregate results based on time line. Sadri et al. [284] propose SQL-TS, an extension of the SQL language to express sequence queries over time-series data.

15.2.2 Wide area Sensor Networks

There is little research on wide area sensor databases while the Intel IrisNet project has done a major work to address the challenges to support a large number of sensors and high query volumes in wide area sensor databases. The sensor database is partitioned across multiple sites that operate in parallel. User queries are directed to the sites that contain the results. A site manager called organizing agent works in each site. Communications with the sensors are through sensor proxies called sensing agents, which are the powered and internet connected PCs. Sensor proxies collect, filter, and aggregate data then send update queries to the sites that own the data [270, 273].

To make queries flexible, easy to use and to support the growing trends to XML standard in the IrisNet XML database system is used. XPATH or XSLT for querying, and SixDML or XUpdate for updates are used. The distributed site hierarchy is represented as an XML document. The data in sensor networks is fairly diverse and heterogeneous, and hard to capture in a rigid data model. The schema of the data needs to be constantly adapted to support the growing and diversified needs of the users, and evolving capabilities of the sensors. Dynamic insertion and deletion of new fields is easy in XML. Besides, as sensors take data from a geographic location, it is quite natural to organize the sensor data into a geographic/political-boundary hierarchy (as depicted in Figure 1). Representing and making use of such a hierarchy is quite natural in XML, but very challenging in the relational, or an object-relational data model [270].

Sensor data is placed in any number of host nodes and near to the sensors but for efficient querying data are cached to anywhere depending on the needs of the queries and applications. An efficient partitioning and caching strategy supporting partial match caching is presented which ensures that even partial matches on cached data can be exploited and that correct answers are returned. A dynamic self starting distributed query is supported where the queries based on the XPATH query statement and the XML document find the least common ancestor (LCA) of the hierarchical database fragments where query results exist and a DNS like server finds the IP address of the LCA. Moreover, a novel query-evaluate-gather based on XSLT determines which data of the local database is part of the query result and how to collect the missing data [270].

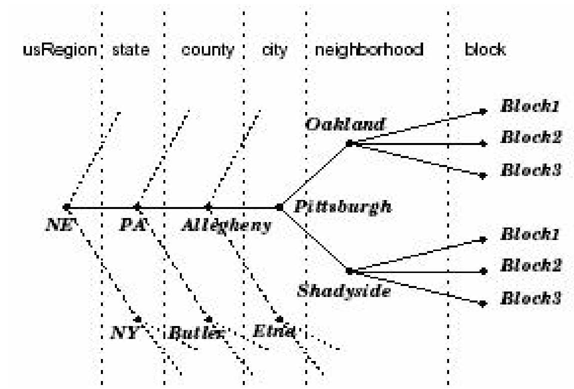

Figure 1: Site hierarchy [270]

The IrisNet has similar structure with DNS [283] and LDAP [288] but DNS, and LDAP support a small set of lookup queries whereas IrisNet supports rich query languages. Latest works on peer-to-peer databases [269, 274] are quite similar to the IrisNet works. The IrisNet is mostly hierarchical but for performance reasons, the participating sites are treated as co-operating peers. The IrisNet differs from peer-to-peer databases because of its query processing part, caching, and partitioning strategies.

15.3 Future Directions

The analysis of current querying techniques for sensor networks opens a plethora of new research directions at the boundary of sensor database systems and networking: We find that conventional sensor networks generally use SQL like declarative language while their wide area counterpart uses XML and XPATH/XSLT query language. So, coordination is needed between them to work together. Some proxy layer can work in the terminal base stations to convert XML to SQL. Also XML query can be utilized in the power constrained sensor networks in future. We envision one step further integrating conventional and wide area sensor databases to provide a common query language interface so that no proxy layer/converter is needed. Besides, very changing nature of sensor data can well fit into XML representation. So, we suggest XML and XPATH queries in both wide and local area sensor networks.

We see that some of the sensor network applications treat sensor data as a stream and some other treat as continuous. Hence, a generalized DBMS is required that can handle both types of application and situation. Since the sensor node supports limited storage, the code size should be small. Alternatively, the base/central node can load appropriate modules to the sensor nodes depending on the application. This on-demand loading of modules can use the concept of swapping/paging in the base station hard drive, which requires communication causing much power consumption. So, the algorithms should be power efficient.

The caching infrastructure used in the current wide area querying is not fully adequate for caching results from aggregate queries. Therefore, providing support for view-based semantic caching is necessary. In wide area sensor networks, different data mining approaches can also be utilized over historical sensor data to generate historical trends, which can provide better answers to user queries. For example, historical trends will allow a user to know how fast a parking space is filling up. None of the current querying techniques is concerned about database security. Integration of security mechanisms inside database can prevent unauthorized user from querying.

The underlying query processing architecture for a sensor network is an important consideration affecting its performance, scalability, and applicability. In essence, current and future capabilities of sensor networks mostly depend on the query processing architecture. In this paper, we identify the design objectives and challenges related to query processing over sensor networks and to this end investigate the key querying techniques with their relative advantages and limitations. The analysis of these techniques has enabled us to set a plethora of future research directions. The emphasis is placed on interoperability and integration issues related to conventional and wide are sensor network databases with an aim of pervasive deployment of sensor network applications.

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16 Conclusions

Day by day With the pace of technology huge number of exciting and useful sensor networks applications are emerging. In near future sensor networks will be an integral part of our everyday life. Sensor networks will be an integral component in most industries, agriculture, medical and home applications. To make sensor networks truly beneficial sensor networks need to be robust, power efficient, long-lived, resistive to failure, resistive to topology changes. The protocols needs to be well designed, stable and robust. Moreover, the costing should be a minimum. Though huge research is going on in sensor networks, still there are huge challenges. This survey addressed most of the researches in each category besides provides an in depth analysis of the current limitations and future research directions in each category. The analysis will lead one to know sensor networks properly and find future requirements for sensor networks. We encourage future research to the unexplored areas addressed in the survey.