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SENSOR NETWORKS

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Summary

This paper which has to do with sensor networks consists of five chapters. After an extended research on the internet, the most interesting information is presented in these pages.

To begin with, the first chapter refers to the workplace applications of sensor networks. The current generation of interactive devices and networks foster a wide class of interactive ubiquitous computing applications . The recent trend to integrate wireless networking into interactive devices such as PDAs, cellular phones, and portable computers has led to the availability of information such as news and stock quotes, as well as services such as email, appointment tracking, and multimedia content from any location at any time. These applications have significantly improved workplace productivity, despite the fact that human participation is often required in the compute loop. These applications have traditionally interacted with virtual content such as email, financial records, and text documents.

In the second chapter the energy conservation at the link and network layers is presented. Sensor networks promise to place sensors in the physical world to gather information, communicate, and act. All of these steps consume energy. With limited battery capacity, sensor networks are characterized by the situation where each bit sent brings that node closer to death . Some sensor networks today add energy harvesting with solar panels or other more experimental methods, but even there careful use of energy is essential to an operational system.

In the third part we can find out how the sensor networks are placed in the field of habitat monitoring. Habitat and environmental monitoring represent a class of sensor network applications with enormous potential benefits for scientific communities and society as a whole. Instrumenting natural spaces with numerous networked microsensors can enable long-term data collection at scales and resolutions that are difficult, if not impossible, to obtain otherwise.
The intimate connection with its immediate physical environment allows each sensor to provide localized measurements and detailed information that is hard to obtain through traditional instrumentation.

Finally in chapter four new applications are identified and the importance of sensor networks in today's life is being mentioned. Networked microsensors technology is a key technology for the future. In September 1999 , *Business Week* heralded it as one of the 21 most important technologies for the 21st century. Cheap, smart devices with multiple onboard sensors, networked through wireless links and the Internet and deployed in large numbers, provide unprecedented opportunities for instrumenting and controlling homes, cities, and the environment. In addition, networked microsensors provide the technology for a broad spectrum of systems in the defense arena, generating new capabilities for reconnaissance and surveillance as well as other tactical applications.

Περίληψη

Αυτή η εργασία αποτελείται από πέντε κεφάλαια πραγματεύεται τις εφαρμογές των δικτύων αισθητήρα.

Το πρώτο κεφάλαιο αναφέρεται στην εφαρμογή των δικτύων αυτών στους χώρους εργασίας. Η γενιά των σύγχρονων κατασκευών υιοθετεί ευρύτατα διαδραστικές υπολογιστικές εφαρμογές. Η σύγχρονη τάση να ενσωματώνονται ασύρματα δίκτυα σε συσκευές όπως PDA κινητά τηλέφωνα και φορητούς υπολογιστές έχει οδηγήσει στην αφθονία πληροφοριών όπως τα νέα και οι τιμές των μετοχών καθώς επίσης και σε υπηρεσίες όπως το ηλεκτρονικό ταχυδρομείο , τα οικονομικά αρχεία και τα δεδομένα κειμένου.

Το δεύτερο κεφάλαιο αναφέρεται στη διατήρηση ενέργειας στα δίκτυα αισθητήρα. Αυτά πρόκειται να χρησιμοποιηθούν για τη συλλογή πληροφοριών , την επικοινωνία και τη δράση στο φυσικό περιβάλλον με τη τοποθέτηση αισθητήρων. Όλες αυτές οι ενέργειες απαιτούν την κατανάλωση ενέργειας. Με ελάχιστη χωρητικότητα μπαταρίας τα δίκτυα αισθητήρα χαρακτηρίζονται από το αποτέλεσμα της γρήγορης φθοράς των κόμβων με την αποστολή του κάθε bit. Κάποια δίκτυα αισθητήρα σήμερα προσφέρουν ακόμα και τη συλλογή ενέργειας με ηλιακούς συλλέκτες η άλλες πιο πειραματικές μεθόδους , όμως ακόμα και η προσεκτική χρήση ενέργειας αυτών είναι απαραίτητη σε ένα λειτουργικό σύστημα.

Στο τρίτο κεφάλαιο μπορεί κάποιος να πληροφορηθεί σχετικά με την εφαρμογή των εν λόγω δικτύων στην παρακολούθηση του φυσικού περιβάλλοντος. Η παρακολούθηση του φυσικού περιβάλλοντος αντιπροσωπεύει μια τάξη των εφαρμογών των δικτύων αισθητήρα με πιθανά μεγάλα οφέλη για την επιστημονική κοινότητα και τη κοινωνία γενικά. Τοποθετώντας όργανα στο φυσικό χώρο με πολλούς δικτυωμένους αισθητήρες μπορούμε να πετύχουμε μακροπρόθεσμα συλλογή πληροφοριών που διαφορετικά θα ήταν πολύ δύσκολο αν όχι ακατόρθωτο .

Τέλος στο τέταρτο κεφάλαιο αναφέρονται οι νέες εφαρμογές και η σπουδαιότητα στη σημερινή ζωή των δικτύων αισθητήρα. Η τεχνολογία των δικτυωμένων μικροαισθητήρων αποτελεί τη τεχνολογία του μέλλοντος. Το Σεπτέμβριο του 1999 το περιοδικό Business week το ανέφερε σαν μια από τις εικοσιμία πιο σημαντικές τεχνολογίες του 21ου αιώνα. Φτηνές έξυπνες συσκευές με πολλαπλούς ενσωματωμένους αισθητήρες δικτυωμένους διάμεσου ασύρματων συνδέσμων και του internet παρέχουν ευκαιρίες για τον έλεγχο των σπιτιών , των πόλεων και του περιβάλλοντος. Επιπρόσθετα οι δικτυωμένοι μικροσένσορες παρέχουν τη τεχνολογία για ένα ευρύ σύστημα δικτύων στο πεδίο της υπεράσπισης δημιουργώντας νέες δυνατότητες για παρακολούθηση και αναγνώριση ατόμων.

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1.0 Workplace applications of sensor networks

1.1 introduction

The current generation of interactive devices and networks foster a wide class of interactive ubiquitous computing applications [1]. The recent trend to integrate wireless networking into interactive devices such as PDAs, cellular phones, and portable computers has led to the availability of information such as news and stock quotes, as well as services such as email, appointment tracking, and multimedia content from any location at any time. These applications have significantly improved workplace productivity, despite the fact that human participation is often required in the compute loop. These applications have traditionally interacted with virtual content such as email, financial records, and text documents.

Today millions of sensors are scattered throughout workplaces in both industrial and non-industrial office environments. These sensors include HVAC-monitoring devices such as thermometers, barometers, and moisture gauges, safety monitors such as
carbon monoxide and smoke detectors, security monitors such as motion and glass break detectors, and access control devices such as RFID badge readers. In most cases, sensors
are deployed for a specific application and access to sensor output is only available locally. A person typically must walk up to a sensor to obtain its current reading. In some cases, sensors may be wired to a nearby closed-loop monitoring station, but such
monitoring stations are generally application-specific. While these sensors serve useful purposes to the individuals who deploy them, in practice each sensor is typically used only for a single specific monitoring application. By networking these devices to provide ubiquitous access to remote information and actuation capabilities, many new applications emerge. The advent of inexpensive,
low-power wireless sensors and self-configuring network technologies allows sensors to be easily deployed in a ubiquitous, ad-hoc manner. These deployments interface to the physical work and promise to make everyday tasks easier, enhancing
our ability to examine and optimize the environments in which we live and work. Recent advances in sensor hardware make it feasible to deploy small sensors in office environments, but many challenges remain. This chapter looks at two case studies in detail to explore those challenges: an application to assist workers in finding conference rooms, and another that guides visitors around an office environment. In addition to illustrating the challenges in
developing and evaluating prototypes of real applications, these applications illustrate problems paramount to the office environment. The conference room application must integrate with existing networking and sensor infrastructure and interact with users in a
useful manner. The visitor guidance application must consider human movement constraints and be easy to deploy and maintain.

In addition, both applications require self-configuring wireless networks and low power operation (as do many other applications in sensor networks). These requirements might be surprising for in-building applications where power and networking are both comparatively plentiful. However, it is not always feasible to locate sensors near power or network outlets. Additional wiring would quickly exceed the cost-benefit ratio of these ad hoc applications. Even in new construction, each wired network port and outlet has a cost that must be justified. Thus we see low-power operation, energy harvesting, and wireless as necessities even in relatively wired environments. However, there is also an opportunity to leverage these sparsely available infrastructural resources for the benefit of the entire network.

1.2 Hardware for Workplace Sensor Network Deployment

Four types of hardware platforms with heterogeneous capabilities are commonly used in the deployment of workplace sensor network applications: sensor nodes, display nodes, gateway nodes, and handheld nodes. These hardware platforms are tailored for
sensing, human interaction with the sensor network, and interfacing the sensor network with workplace networks, and so they provide a mix of processing power and input/output capabilities. Each of the hardware building blocks should be viewed as representatives for a class of devices. Table 1 provides a comparative description of these devices.

Table1

Node Type	Sample "Name" & Size	Typical Application Sensors	Radio Bandwidth (Kbps)	MIPS	FLASH	RAM	Typical Active Energy (mW)	Typical Sleep Energy (uW)	Typical Duty Cycle (%)
Generic Sensing Platform	Mote 1-10cm³	General Purpose Sensing and Communications Relay	<100 kb/s	< 10	< 0.5 Mb	< 10 Kb	3V * 10-15mA	3V*10uA	1-2%
High Bandwidth Sensing	Imote 1-10cm³	Rich Sensing (Video, Acoustic, and Vibration)	~ 500 kb/s	< 50	< 10 Mb	< 128 Kb	3V*60mA	3V*100uA	5-10%
Gateway	Stargate >10cm³	High Bandwidth Sensing and Communications Aggregation. Gateway node.	> 500 kb/s – 10 Mb/s	> 100			3V*200mA	3V*10mA	> 50%

In figures 1 to 5 some kinds of above mentioned nodes are displayed. In particular in figure 1 we can see an example of the Berkeley mote that is commonly used in sensor network research and applications.

In figure 2 we can see the internal and external view of a button box node. In figures 3 and 4 there is the LCD display node and the candy compact flash mote respectively. The button box node includes a Mica-2 mote and is powered by two AAA batteries. It provides a simple interface that includes two buttons for input and three LEDs and a buzzer for output. While the button box is useful in many applications, a richer interface is sometimes required. The LCD display node (Figure 3) is a small, low-power wrist-watch form factor node designed to enable limited human interaction with a sensor network.
This device consists of a Mica-2 mote integrated with an LCD capable of showing text and simple graphics and four control buttons. These buttons may be used to trigger the node to a wake up from deep sleep and also allow user

text input. These devices provide an easy and inexpensive method to allow ubiquitous display and user interaction of information in the workplace.

In figure 5 we can see an Xscale(TM) architecture based gateway node. This is an example of a gateway node , the Stargate platform ,which includes a 400 MHz Intel XScale™ architecture-based processor, tens of megabytes of RAM and up to gigabytes of persistent storage.

figure 1

figure 2

figure 3

figure 4


figure 5

2.0 Energy conservation in sensor networks at the link and network layers

2.1 introduction

Sensor networks promise to place sensors in the physical world to gather information, communicate, and act. All of these steps consume energy. With limited battery capacity, sensor networks are characterized by the situation where each bit sent brings that node closer to death [2]. Some sensor networks today add energy harvesting with solar panels or other more experimental methods, but even there careful use of energy is essential to an operational system.

Given a limited amount of energy or a limited recharge rate, energy conservation becomes a goal. A successful sensor network will minimize energy consumption at all levels of the system, from the application down to the hardware itself. This chapter considers network-level opportunities for energy conservation, with emphasis on the media-access control (MAC) level, topology control protocols, and routing-level issues.

2.2 Radio transmission power control

Transmission power control is important for several reasons: first, adjusting power can be important to guarantee connectivity. Second, since transmission power indicates a radio's “footprint”, controlling power is essential to managing density and encouraging spatial reuse of spectrum. Finally, minimizing transmission power can reduce energy consumption, both directly, by requiring less power to send, and indirectly, by reducing contention with other transmitting nodes.

Guaranteeing connectivity and managing density are related problems. By balancing connectivity and density wireless networks maximize spatial reuse of the spectrum. Power control is a key component to this process. There is a very, very large body of literature around analysis and protocol design for wireless power control. Many approach the subject from the MAC layer. A representative

MAC protocol that considers power control is PCMA [3]. It focuses on optimizing spatial channel reuse, and extends an RTS/CTS mechanism to support variable power. They demonstrate about 50% better throughput when nodes and traffic are clustered and power control is enabled.

Efficient spatial use also affects the fundamental performance limits of the sensor network. For example, Gupta and Kumar's work establishes a theoretical bound on the capacity of a network indicating that wireless network capacity tracks $\Omega(n)^{1/2}$ as the number of nodes increase, assuming optimal transmission power and uniform distributions of sources and sinks [4]. Selection of optimal transmission power is necessary for their results.

Fewer researchers focus on power control to reduce energy consumption. The focus is most often on connectivity and spatial reuse because those are more pressing issues in systems design, particularly at longer ranges. The benefits of short-range transmission have been observed by Kaiser and Pottie, both due to the d2 cost of longer-distance transmission, and because of the opportunity to trade local processing for transmission [5]. Radio transmission power can be a significant part of energy consumption at short ranges, but without care other component costs can dominate. For example, the CC1000 radio is widely used in sensor networks on platforms such as Mica2 Motes, and its output power ranges over a factor of 5 (from 5ñ27mA) [6]. However, the fixed cost of listening makes transmission power differences insignificant at low duty cycles. If 2% of time is spent transmitting, for example, the maximum energy savings is only 8%. Avoiding collisions by spatial reuse doubles the savings, by comparison, since after a collision both parties must retransmit.

Figure 6 illustrates these concepts by considering two transmission powers, r and R, where R ≈3r. For communication from node a to d, two one can either transmit in one hop at full power (R), or in three hops a-b-c-d, each at reduced power of r. Using a simple d2 energy model, the relative costs of these transmissions are $1 *3^2 = 9$ for one hop with R and $3 *1^2 = 3$ for three hops with r, demonstrating the possible energy conservation from shorter, multi-hop communication.

This example also shows the possibility for spatial reuse and reduced contention enabled by lower-power transmission. With strength-r transmissions, concurrent communications are possible between nodes a-b and nodes d-e, while if node a communicates directly with node d at strength R, node d must be silent to avoid interference. Of course these examples are greatly simplified compared to the real world, where radio propagation is not spherical or symmetric, and listening and other costs must be considered (as described in the next section). However, it illustrates the principles of power control.

Figure shows the reduced contention and increased spatial reuse with short-range communications as a result of less interfering nodes.

When power control is considered for energy savings it is often viewed as part of the routing layer. An example protocol from this domain is LEACH [7]. Rather than sending data directly to a central site, nodes form clusters. Data is sent via a short hop to the cluster head, then via a long hop to the sink. By rotating cluster heads over time, energy consumption is reduced and distributed evenly, allowing a five-fold increase in network lifetime.

Systematic studies of the interactions between power control and routing protocols indicate the importance of considering interactions to ensure a reliable overall system [8].

2.3 Medium access control

Lets examine the energy conservation opportunities at the MAC level. For our purposes, we will assume that transmission power has been fixed. This leaves four areas of energy consumption that can be avoided: collisions consume energy by corrupting otherwise good packets. Idle listening is a major source of energy consumption when the radio is kept powered on for potential incoming transmissions. Overhearing transmitting packets consumes energy in a busy network when a node spends effort receiving packets destined to other nodes. Finally, control packets consume energy that is not directly sending useful data. A number of approaches have been proposed to reduce each of these costs: TDMA, and contention-based protocols with scheduled contention periods,
asynchronous, paging channels, and low-power listening.

Several MAC-level approaches have been proposed to reduce these costs. The first class is schedule-based protocols. Time-division multiple-access protocols can avoid collisions, idle listening, and overhearing by scheduling transmit and listen periods. TDMA protocols require strict time synchronization, often provided by infrastructure such as a base station. The infrastructure mode of IEEE-802.11 incorporates a contention-free interval, which adopts a TDMA-like structure coordinated by the access point [9], avoiding all three kinds of overhead. Bluetooth behaves similarly in a cluster, called piconet, where a master polls each slavse for possible transmissions. Inter-cluster communication and interference are handled by CDMA. Sohrabi and Pottie have proposed a peer-to-peer transmission scheduling protocol for sensor networks [10]. Their approach avoids base-stations, but it depends on assigning different channels (CDMA or FDMA) to any interfering links to allow concurrent transmissions, and as a result has lower channel utilization.

Contention-based protocols are a second class of MAC protocols. They relax the tight synchronization requirements of TDMA protocols and use carrier-sense multiple access (CSMA) techniques to provide more flexibility in multi-hop communications and better robustness to topology changes. However, because these protocols contend to access the channel, collisions occur, and basic protocols in this class have costs for idle listening and overhearing. IEEE-802.11 ad hoc mode is a very widely used contention-based protocol. It uses carrier-sensing and randomized back-offs to reduce the likelihood of collisions [9]. To reduce idle listening, it defines a power save mode (PSM), allowing nodes to periodically enter sleep state. The PSM assumes a single-hop network and so time synchronization is easy. In multi-hop operation, it may have problems in clock synchronization, neighbor discovery and network partitioning [11].

Overhearing is another source of energy waste. PAMASfirst observed the costs of overhearing and suggested using two channels, one for control traffic and the other for data traffic [12]. By keeping the data channel off when packets areexchanged between other nodes overhearing can be avoided. Scheduled contention protocols are a subset of contention based protocols. Besides the PSM in 802.11 ad hoc mode, SMAC is a second protocol in this class [13], [14]. In S-MAC each node adopts a listen/sleep cycle. Contention occurs only during a brief listen period, reducing the cost of idle listening. Figure 7 shows how two nodes exchange packets with the listen/sleep cycles. When there is no data, nodes enters the sleep mode after the brief listening. Otherwise, they use their sleep time to transmit data packets. During the data transmission, nodes other than the source and destinations sleep to avoid energy consumed due to overhearing (a generalization of PAMAS to in-channel signaling). S-MAC maintains a loosetime synchronization between nodes to synchronize schedules, and it allows nodes to adopt multiple schedules, if necessary, to support distributed, multi-hop operation. Recently adaptive listen [14] and T-MAC [15] have been proposed to improve multi-hop transmission with sleep-cycled MAC protocols.

Asynchronous schemes are a fourth class of MAC protocols. Tseng et al. [11] proposed asynchronous wake-up schemes to extend the 802.11 PS mode into multi-hop operations. Their basic idea is to design wake-up patterns that guarantee neighboring nodes have overlapping listen intervals no matter how large their clock differences are. Zheng et at. [16] proposed an optimal design of the asynchronous sleep patterns to minimize wake-up time by formulating the problem as the block design in combinatorics. Asynchronous wake-up schemes completely remove the requirement of time synchronizations. Its major drawback is the inefficiency in broadcasting, since all nodes wake up independently.

Paging channels are another approach to reduce energy consumption: the primary radio is left off when there is no traffic, and a secondary low-power radio (the paging channel) is used to wake up nodes when data needs to be sent. STEM [17] is an on-demand wake-up protocol using a second radio as a paging channel. In addition to using a low-power paging radio, STEM further reduces energy consumption by letting the paging radio periodically poll the medium for traffic. A sender needs to send a wake-up signal that is at least the length of the period. An advantage of using a second radio is the ability to completely avoid interference to the possible transmissions on the main radio.

This approach for low-power listening has been generalized to operate as the primary energy conservation mechanisms with a single radio [18], [19]. A sleeping node periodically wakes up and briefly polls the medium. It stays in active mode only when activity is detected. A sender wakes up a receiver by sending packets with a preamble that is as long as the polling period. Figure 3 shows the packet exchanges in low power listening. The benefit of low-power listen is that very brief polling is possible, as little as 3ms on Mica2 motes [18], with most of the delay being time for the radio's crystal to stabilize. The disadvantage is that transmitting nodes must precede packets with extremely long preambles. It increases control overhead and reduces channel utilization, especially when traffic is heavy. On-demand wake-up offers the most aggressive reduction in listen time. For very low duty cycle networks (less than a few percent) and light traffic it appears quite attractive.

In summary, schedule-based MAC protocols, such as TDMA, avoid collisions, and are easy to reduce idle listening and overhearing. However they can be a poor match Fig. 8. Node equivalence in dense sensor networks (examples from [20]). to multi-hop networks because of uneven energy usage due to clustering and the need for strict time synchronization. Contention protocols do not have these disadvantages, but basic protocols consume energy in collisions, idle listening and overhearing. Versions of contention protocols reduce each of these costs, with four techniques to reduce idle listening: scheduled contention periods, asynchronous, paging channels, and low-power listening, each with its own advantages and disadvantages.

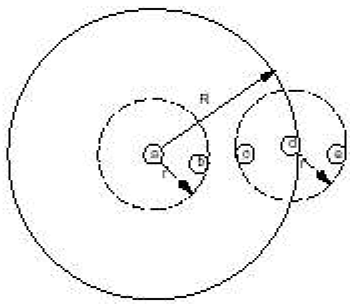

Figure 6. Control of transmission power to promote spatial reuse and reduce energy requirements.

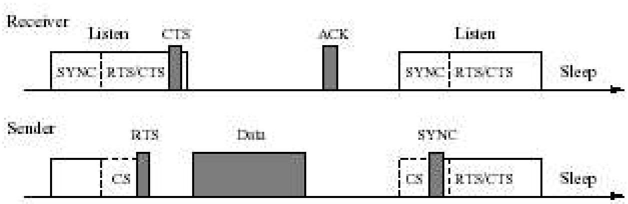

Figure 7. Packet exchanges in S-MAC with listen/sleep cycles. CS stands for carrier sense.

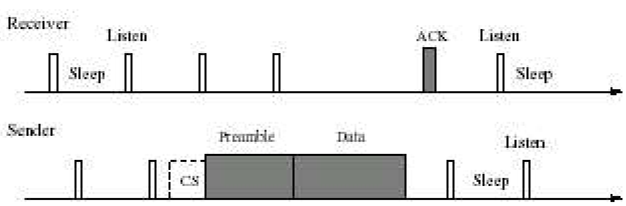

Fig. 8. Packet exchanges in low-power listening. CS stands for carrier sense.

<u>2.4 energy conservation in today's and tomorrow's applications</u>

Having considered opportunities to conserve energy at each of these layers of the system, we conclude by placing them in the context of sensor networks that are being deployed today and that we expect may be deployed in years to come.

Habitat monitoring is a representative of current state-of the-art for sensor network applications today [33]. Several dozens of Mica2 motes are placed to monitor a 500x500m area, augmented by a few computers with additional electrical and compute power and connectivity to the Internet. Deployment is done with some care to insure sufficient radio and sensing coverage.

It is informative to compare energy conservation in such an application. Radio transmission power is selected off-line, with deployment density and configuration in mind, to insure connectivity. On-line radio-power control is not necessary. Since target lifetimes are several months or an entire season, MAC-level power control is critical, using either S-MAC or low-power listening. The network is not dense enough to warrant on-line topology control, and with only a single extraction point for data, routing options are limited.

While this application indicates current practice, it is in many ways limited by current cost and deployment constraints. Today's sensors cost a few hundred dollars per node for hardware, and remote deployment, ongoing debugging and development make total costs higher still. As sensor prices fall and the infrastructure matures, denser deployments will become easier, making on-line use of transmission power control and topology control more feasible. Deployment of applications in less remote areas will motivate multiple connections to traditional networks, opening room for energy conserving routing.

3.0 wireless sensor networks for habitat monitoring

3.1 introduction

Habitat and environmental monitoring represent a class of sensor network applications with enormous potential benefits for scientific communities and society as a whole. Instrumenting natural spaces with numerous networked microsensors can enable long-term data collection at scales and resolutions that are difficult, if not impossible, to obtain otherwise.The intimate connection with its immediate physical environment allows each sensor to provide localized measurements and detailed information that is hard to obtain through traditional instrumentation. The integration of local processing and storage allows sensor nodes to perform complex filtering and triggering functions, as well as to apply application-specific or sensor-specific data compression algorithms. The ability to communicate not only allows information and control to be communicated across the network of nodes, but nodes to cooperate in performing more complex tasks, like statistical sampling, data aggregation, and system health and status monitoring [21, 22]. Increased power efficiency gives applications flexibility in resolving fundamental design tradeoffs, e.g., between sampling rates and battery lifetimes. Low-power radios with well-designed protocol stacks allow generalized communications among network nodes, rather than point-to-point telemetry. The computing and networking capabilities allow sensor networks to be reprogrammed or retasked after deployment in the field. Nodes have the ability to adapt their operation over time in response to changes in the environment, the condition of the sensor network itself, or the scientific endeavor.

3.2. Habitat monitoring

Researchers in the Life Sciences are becoming increasingly concerned about the potential impacts of human presence in monitoring plants and animals in field conditions. At best it is possible that chronic human disturbance may distort results by changing behavioral patterns or distributions, while at worst anthropogenic disturbance can seriously reduce or even destroy sensitive populations by increasing stress, reducing breeding success, increasing predation, or causing a shift to unsuitable habitats. While the effects of disturbance are usually immediately obvious in animals, plant populations are sensitive to trampling by even well-intended researchers, introduction of exotic elements through frequent visitation, and changes in local drainage patterns through path formation.

Disturbance effects are of particular concern in small islandsituations, where it may be physically impossible for researchers to avoid some impact on an entire population. In addition, islands often serve as refuge for species that cannot adapt to the presence of terrestrial mammals, or may hold fragments of once widespread populations that have been extirpated from much of their former range.

Seabird colonies are notorious for their sensitivity to human disturbance. Research in Maine [2] suggests that even a 15 minute visit to a cormorant colony can result in up to 20% mortality among eggs and chicks in a given breeding year. Repeated disturbance will lead to complete abandonment of the colony. On Kent Island, Nova Scotia, researchers found that Leach's Storm Petrels are likely to desert their nesting burrows if they are disturbed during the first 2 weeks of incubation.

Sensor networks represent a significant advance over traditional invasive methods of monitoring. Sensors can be deployed prior to the onset of the breeding season or other sensitive period (in the case of animals) or while plants are dormant or the ground is frozen (in the case of botanical studies). Sensors can be deployed on small islets where it would be unsafe or unwise to repeatedly attempt field studies. The results of wireless sensor-based monitoring efforts can be compared with previous studies that have traditionally ignored or discounted disturbance effects.

Finally, sensor network deployment may represent a substantially more economical method for conducting long-term studies than traditional personnel-

rich methods. Presently, a substantial proportion of logistics and infrastructure mustbe devoted to the maintenance of field studies, often at some discomfort and occasionally at some real risk. A “deploy ’em and leave ’em” strategy of wireless sensor usage would limit logistical needs to initial placement and occasional servicing.
This could also greatly increase access to a wider array of study sites, often limited by concerns about frequent access and habitability.

3.3 Great Duck Island

The College of the Atlantic (COA) is field testing in-situ sensor networks for habitat monitoring. COA has ongoing field research programs on several remote islands with well established on-site infrastructure and logistical support.
Great Duck Island (GDI) (44.09N,68.15W) is a 237 acre island located 15 km south of Mount Desert Island, Maine. The Nature Conservancy, the State of Maine and the College of the Atlantic hold much of the island in joint tenancy. At GDI, we are primarily interested in three major questions in monitoring the Leach’s Storm Petrel [23]

3.4 System architecture

This is the description of the system architecture, functionality of individual components and how they operate together.

A tiered architecture have been developed. The lowest level consists of the sensor nodes that perform general purpose computing and networking in addition to application-specific sensing. The sensor nodes may be deployed in dense patches that are widely separated. The sensor nodes transmit their data through the sensor network to the sensor network gateway. The gateway is responsible for transmitting sensor data from the sensor patch through a local transit network to the remote base station that provides WAN connectivity and data logging. The base station connects to database replicas across the internet. Finally, the data is displayed to scientists through a user interface. Mobile devices may interact with any of the networks– whether it is used in the field or across the world connected to a database replica. The full architecture is depicted in Figure 9.

The lowest level of the sensing application is provided by autonomous sensor nodes. These small, battery-powered devices are placed in areas of interest. Each sensor node collects environmental data primarily about its immediate surroundings. Because it is placed close to the phenomenon of interest, the sensors can often be built using small and inexpensive individual sensors. High spatial resolution can be achieved through dense deployment of sensor nodes. Compared with traditional approaches, which use a few high quality sensors with sophisticated signal processing, this architecture provides higher robustness against occlusions and component failures.

The computational module is a programmable unit that provides computation, storage, and bidirectional communicationwith other nodes in the system. The computationalmodule interfaces with the analog and digital sensors on the sensor module, performs basic signal processing (e.g., simpletranslations based on calibration data or threshold filters), and dispatches the data according to the application's needs. Compared with traditional data logging systems, networked sensors offer two major advantages: they can be retasked in the field and they can easily communicate with the rest of the system. In-situ retasking allows the scientists to refocus their observations based on the analysis of the initial results. Suppose that initially we want to collect the absolute temperature readings; however after the initial interpretation of the data we might realize that significant temperature changes exceeding a defined threshold are most interesting.

Individual sensor nodes communicate and coordinate with one another. The sensors will typically form a multi hop network by forwarding each other's messages, which vastly extends connectivity options. If appropriate, the network can perform in-network aggregation (e.g., reporting the average temperature across a region). This flexible communication structure allows us to produce a network that delivers the required data while meeting the energy requirements.

Ultimately, data from each sensor needs to be propagated to the Internet. The propagated data may be raw, filtered, or processed data. Bringing direct wide area connectivity to each sensor path is not feasible – the equipment is too costly, it requires too much power and the installation of all required equipment is quite intrusive to the habitat. Instead, the wide area connectivity is brought to a base station, adequate power and housing for the equipment is provided.
The base station may communicate with the sensor patch using a wireless local area network. Wireless networks are particularly advantageous since often each habitat involves monitoring several particularly interesting areas, each with its own dedicated sensor patch.

Each sensor patch is equipped with a gateway which can communicate with the sensor network and provides connectivity to the transit network. The transit network may consist of a single hop link or a series of networked wireless nodes, perhaps in a path from the gateway to base station. Each transit network design has different characteristics with respect to expected robustness, bandwidth, energy efficiency, cost, and manageability.

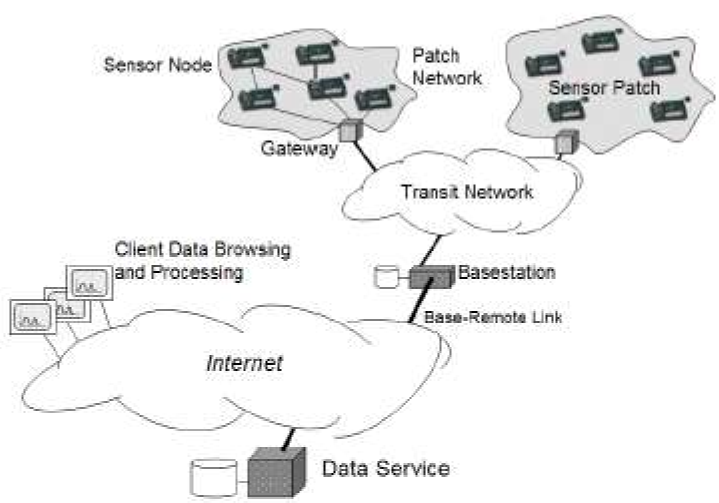

Figure 9: System architecture for habitat monitoring

4.0 Evolution , Opportunities , Challenges

4.1 introduction

Networked microsensors technology is a key technology for the future. In September 1999 [24], *Business Week* heralded it as one of the 21 most important technologies for the 21st century. Cheap, smart devices with multiple onboard sensors, networked through wireless links and the Internet and deployed in large numbers, provide unprecedented opportunities for instrumenting and controlling homes, cities, and the environment. In addition, networked microsensors provide the technology for a broad spectrum of systems in the defense arena, generating new capabilities for reconnaissance and surveillance as well as other tactical applications.

Smart disposable microsensors can be deployed on the ground, in the air, under water, on bodies, in vehicles, and inside buildings. A system of networked sensors can detect and track threats (e.g., winged and wheeled vehicles, personnel, chemical and biological agents) and be used for weapon targeting and area denial. Each sensor node will have embedded processing capability, and will potentially have multiple onboard sensors, operating in the acoustic, seismic, infrared (IR), and magnetic modes, as well as imagers and microradars. Also onboard will be storage, wireless links to neighboring nodes, and location and positioning knowledge through the global positioning system (GPS) or local positioning algorithms.

Networked microsensors belong to the general family of sensor networks that use multiple distributed sensors to collect information on entities of interest. Table 2 summarizes the range of possible attributes in general sensor networks.
Current and potential applications of sensor networks include: military sensing, physical security, air traffic control, traffic surveillance, video surveillance, industrial and manufacturing automation, distributed robotics, environment monitoring, and building and structures monitoring. The sensors in these applications may be small or large, and the networks may be wired or wireless. However, ubiquitous wireless networks of microsensors probably offer the most potential in changing the world of sensing [25]

Sensors	*Size*: small (e.g., micro-electro mechanical systems (MEMS)), large (e.g., radars, satellites) *Number*: small, large *Type*: passive (e.g., acoustic, seismic, video, IR, magnetic), active (e.g., radar, ladar) *Composition or mix*: homogeneous (same types of sensors), heterogeneous (different types of sensors) *Spatial coverage*: dense, sparse *Deployment*: fixed and planned (e.g., factory networks), ad hoc (e.g., air-dropped) *Dynamics*: stationary (e.g., seismic sensors), mobile (e.g., on robot vehicles)
Sensing entities of interest	*Extent*: distributed (e.g., environmental monitoring), localized (e.g., target tracking) *Mobility*: static, dynamic *Nature*: cooperative (e.g., air traffic control), non-cooperative (e.g., military targets)
Operating environment	Benign (factory floor), adverse (battlefield)
Communication	*Networking*: wired, wireless *Bandwidth*: high, low
Processing architecture	Centralized (all data sent to central site), distributed (located at sensor or other sites), hybrid
Energy availability	Constrained (e.g., in small sensors), unconstrained (e.g., in large sensors)

Table 2

4.2 technology trends

Current sensor networks can exploit technologies not available 20 years ago and perform functions that were not even dreamed of at that time. Sensors, processors, and communication devices are all getting much smaller and cheaper. Commercial companies such as Ember, Crossbow, and Sensoria are now building and deploying small sensor nodes and systems. These companies provide a vision of how our daily lives will be enhanced through a network of small, embedded sensor nodes. In addition to products from these companies, commercial off-the-shelf personal digital assistants (PDAs) using Palm or Pocket PC operating systems contain significant computing power in a small package. These can easily be "ruggedized" to become processing nodes in a sensor network. Some of these devices even have built-in sensing capabilities, such as cameras. These powerful processors can be hooked to MEMS devices and machines along with extensive databases and communication platforms to bring about a new era of technologically sophisticated sensor nets.

Wireless networks based upon IEEE 802.11 standards can now provide bandwidth approaching those of wired networks. At the same time, the IEEE has noticed the low expense and high capabilities that sensor networks offer. The organization has defined the IEEE 802.15 standard for personal area networks (PANs), with “personal networks” defined to have a radius of 5 to 10 m. Networks of short-range sensors are the ideal technology to be employed in PANs. The IEEE encouragement of the development of technologies and algorithms for such short ranges ensures continued development of low-cost sensor nets [26]. Furthermore, increases in chip capacity and processor production capabilities have reduced the energy per bit requirement for both computing and communication. Sensing, computing, and communications can now be performed on a single chip, further reducing the cost and allowing deployment in ever larger numbers.

Looking into the future, we predict that advances in MEMS technology will produce sensors that are even more capable and versatile. For example, Dust Inc., Berkeley, CA, a company that sprung from the late 1990s Smart Dust research project [27] at the University of California, Berkeley, is building MEMS sensors that can sense and communicate and yet are tiny enough to fit inside a cubic millimeter. A Smart Dust optical mote uses MEMS to aim submillimeter-sized mirrors for communications. Smart Dust sensors can be deployed using a 3 10 mm “wavelet” shaped like a maple tree seed and dropped to float to the ground. A wireless network of these ubiquitous, low-cost,disposable microsensors can provide close-in sensing capabilities in many novel applications (as discussed in Section IV).

Table 3 compares three generations of sensor nodes; Fig. 10 shows their sizes.

	Yesterday (1980's – 1990's)	Today (2000 – 2003)	Tomorrow (2010)
Manufacturer	Custom contractors, e.g., for TRSS	Commercial: Crossbow Technology, Inc. Sensoria Corp., Ember Corp.	Dust, Inc. and others to be formed
Size	Large shoe box and up	Pack of cards to small shoe box	Dust particle
Weight	Kilograms	Grams	Negligible
Node architecture	Separate sensing, processing and communication	Integrated sensing, processing and communication	Integrated sensing, processing and communication
Topology	Point-to-point, star	Client server, peer to peer	Peer to peer
Power supply lifetime	Large batteries; hours, days and longer	AA batteries; days to weeks	Solar; months to years
Deployment	Vehicle-placed or air-drop single sensors	Hand-emplaced	Embedded, “sprinkled” left-behind

table 3

figure 10

4.3 New Applications

Research on sensor networks was originally motivated by military applications. Examples of military sensor networks range from large-scale acoustic surveillance systems for ocean surveillance to small networks of unattended ground sensors for ground target detection. However, the availability of low-cost sensors and communication networks has resulted in the development of many other potential applications, from infrastructure security to industrial sensing. The
following are a few examples.

1.0 Infrastructure security
2.0 Environment and habitat monitoring
3.0 Industrial sensing
4.0 Traffic control

5.0 Conclusion

When the concept of DSNs was first introduced more than two decades ago, it was more a vision than a technology ready to be exploited. The early researchers in DSN were severely handicapped by the state of the art in sensors,
computers, and communication networks. Even though the benefits of sensor networks were quickly recognized, their
application was mostly limited to large military systems. Technological advances in the past decade have completely changed the situation. MEMS technology, more reliable wireless communication, and low-cost manufacturing have resulted in small, inexpensive, and powerful sensors with embedded processing and wireless networking capability. Such wireless sensor networks can be used in many new applications, ranging from environmental monitoring to industrial sensing, as well as traditional military applications. In fact, the applications are only limited by our imagination. Networks of small, possibly microscopic sensors embedded in the fabric of society: in buildings and machinery, and even on people, performing automated continual and discrete monitoring, could drastically enhance our understanding of our physical environment.

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www.isi.edu/~johnh/PAPERS/Estrin99e.html

Network sensors--those that coordinate amongst themselves to achieve a larger sensing task--will revolutionize information gathering and processing both in urban environments and in inhospitable terrain. The sheer numbers of these sensors and the expected dynamics in these environments present unique challenges in the design of unattended autonomous sensor networks. These challenges lead us to hypothesize that sensor network coordination applications may need to be structured differently from traditional network applications. In particular, we believe that *localized* algorithms (in which simple local node behavior achieves a desired global objective) may be necessary for sensor network coordination. In this paper, we describe localized algorithms, and then discuss directed diffusion, a simple communication model for describing localized algorithms.

www.isi.edu/~weiye/pub/isi-tr-580.pdf

This paper reviews medium access control (MAC), an enabling technology in wireless sensor networks. MAC protocols control how sensors access a shared radio channel to communicate with neighbors. Battery-powered wireless sensor networks with many nearby nodes challenge traditional MAC design. This paper discusses design trade-offs with an emphasis on energy efficiency. It classifies existing MAC protocols and compares their advantages and disadvantages in the context of sensor networks. Finally, it presents S-MAC as an example of a MAC protocol designed specifically for a sensor network, illustrating one combination of design trade-offs.

www.isi.edu/~johnh/PAPERS/Conner04a.html

In this paper we can find information about hardware that can be used to deploy workplace sensor network applications, followed by a detailed description of applications: conference room monitoring and visitor guidance , and several applications briefly. We then conclude by summarizing our experiences and identifying reusable components in these examples.

www.isi.edu/~johnh/PAPERS/Heidemann04c.html

This chapter surveys network-level approaches to conserve energy in sensor networks. We consider protocols for transmission power control, media access control, topology control, and energy-aware routing, surveying relevant literature and describing approaches that have been considered.

www-net.cs.umass.edu/cs791_**sensor**nets/papers/chong.pdf

This paper traces the history of research in sensor networks over three decades, including two important programs of the Advanced Research Projects Agency (DARPA) spanning period: the Distributed Sensor Networks (DSN) and the Information Technology (SensIT) programs. Technology trends impact the development of sensor networks are reviewed, applications such as infrastructure security, habitat monitoring, and traffic control are presented. Technical challenges network development include network discovery, control routing, collaborative signal and information processing, and querying, and security. The paper concludes by presenting some recent research results in sensor network algorithms, including localized algorithms and directed diffusion, distributed tracking in wireless ad hoc networks, and distributed classification using local agents.

www.isi.edu/~johnh/PAPERS/Estrin99e.html

Network sensors--those that coordinate amongst themselves to achieve a larger sensing task--will revolutionize information gathering and processing both in urban environments and in inhospitable terrain. The sheer numbers of these sensors and the expected dynamics in these environments present unique challenges in the design of unattended autonomous sensor networks. These challenges lead us to hypothesize that sensor network coordination applications may need to be structured differently from traditional network applications. In particular, we believe that *localized algorithms* (in which simple local node behavior achieves a desired global objective) may be necessary for sensor network coordination. In this paper, we describe localized algorithms, and then discuss *directed diffusion*, a simple communication model for describing localized algorithms.

www.antd.nist.gov

A wireless ad hoc sensor network consists of a number of sensors spread across a geographical area. Each sensor has wireless communication capability and some level of intelligence for signal processing and networking of the data. Two ways to classify wireless ad hoc sensor networks are whether or not the nodes are individually addressable, and whether the data in the network is aggregated.

www.snc.sapmi.net/References/Akyildiz2002_SurveySensorNets_01024422.pdf

The current state of the art of sensor networks is captured in this article , where solutions are discussed under their related protocol stack layer sections. This article also points out the open research issues and intends to spark new interests and developments in this field

www.ece.cmu.edu/~adrian/projects/mc2001/mc2001.pdf

This article presents a suite of security building blocks optimized for resourceconstrained environments and wireless communication. SPINS has two secure building blocks: SNEP and _TESLA. SNEP provides the following important baseline security primitives: Data confidentiality, two-party data authentication, and data freshness. particularly hard problem is to provide efficient broadcast authentication, which is an important mechanism for sensor networks. TESLA is a new protocol which provides authenticated broadcast for severely resource-constrained environments.

www.nms.csail.mit.edu/projects/leach/

LEACH (Low Energy Adaptive Clustering Hierarchy) is designed for sensor networks where an end-user wants to remotely monitor the environment. In such a situation, the data from the individual nodes must be sent to a central base station, often located far from the sensor network, through which the end-user can access the data. There are several desirable properties for protocols on these networks

www.cs.cornell.edu/johannes/papers/2003/cidr2003-sensor.pdf

In this paper, we evaluate the design of a query layer for sensor networks. The query layer accepts queries in a declarative language that are then optimized to generate efficient query execution plans with in-network processing which can significantly reduce resource requirements. We examine the main architectural components of such a query layer, concentrating on in-network aggregation, interaction of in-network aggregation with the wireless routing protocol, and distributed query processing. Initial simulation experiments with the ns-2 network simulator show the tradeoffs of our system.

www.ece.cmu.edu/~dawnsong/papers/sia.pdf

In this paper, we propose a novel framework for secure information aggregation in large sensor networks. In our framework certain nodes in the sensor network, called aggregators, help aggregating information requested by a query, which substantially reduces the communication overhead. By constructing efficient random sampling mechanisms and interactive proofs, we enable the user to verify that the answer given by the aggregator is a good approximation of the true value even when the aggregator and a fraction of the sensor nodes are corrupted. In particular, we present efficient

www.tinyos.net/papers/active-nsdi05.pdf

We propose using application specific virtual machines (ASVMs) to reprogram deployed wireless sensor ASVMs provide a way for a user to define an application specific boundary between virtual code and the engine. This allows programs to be very concise hundreds of bytes), making program installation inexpensive. Additionally, concise programs few instructions, imposing very little interpretation overhead. We evaluate ASVMs against current proposals network programming runtimes and show that are more energy efficient by as much as 20%. evaluate ASVMs against hand built TinyOS applications and show that while interpretation imposes a significant execution overhead, the low duty cycles of realistic applications make the actual cost effectively unmeasurable.

www.arri.uta.edu/acs/networks/WirelessSensorNetChap04.pdf

This paper presents the communication networks, wireless sensor networks and smart sensors, physical transduction principles, commercially available wireless sensor systems, self organization, signal processing and decision-making, and finally some concepts for home automation.

www.daveey.netapt.com/work/lecs/rumorroute.pdf

This paper describes and evaluates through simulation a we call Rumor Routing, which allows for queries be delivered to events in the network. Rumor Routing is tunable, and allows for tradeoffs between setup overhead and delivery reliability.

It’s intended contexts in which geographic routing criteria are applicable because a coordinate system is not available or the phenomenon of interest is not geographically correlated.