CHAPTER 1

Algorithms for Wireless Sensor Networks: Present and Future

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1.1 INTRODUCTION

Wireless sensor networks (WSNs) pose new research challenges related to the design of algorithms, network protocols, and software that will enable the development of applications based on sensor devices. Sensor networks are composed of cooperating sensor nodes that can perceive the environment to monitor physical phenomena and events of interest. WSNs are envisioned to be applied in different applications, including, among others, habitat, environmental, and industrial monitoring, which have great potential benefits for the society as a whole. The WSN design often employs some approaches as energy-aware techniques, in-network processing, multihop communication, and density control techniques to extend the network lifetime. In addition, WSNs should be resilient to failures due to different reasons such as physical destruction of nodes or energy depletion. Fault tolerance mechanisms should take advantage of nodal redundancy and distributed task processing. Several challenges still need to be overcome to have ubiquitous deployment of sensor networks. These challenges include dynamic topology, device heterogeneity, limited power capacity, lack of quality of service, application support, manufacturing quality, and ecological issues.

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The capacity to transmit and receive data packets allows both information and control to be shared among sensor nodes but also to perform cooperative tasks, all based on different algorithms that are being specifically designed for such networks. Some of the classes of algorithms for WSNs are briefly described in the following:

- *Centralized algorithms* execute on a central node and usually benefit from a global network knowledge. This type of algorithm is not very common in WSNs because the cost of acquiring a global network knowledge is usually unfeasible in most WSNs.
- *Distributed algorithms* are related to different computational models. In a WSN, the typical computational model is represented by a set of computational devices (sensor nodes) that can communicate among themselves using a message-passing mechanism. Thus, a distributed algorithm is an algorithm that executes on different sensor nodes and uses a message-passing technique.
- *Localized algorithms* comprise a class of algorithms in which a node makes its decisions based on local and limited knowledge instead of a global network knowledge. Thus "locality" usually refers to the node's vicinity [1].

Algorithms for WSNs may also have some specific features such as self-configuration and self-organization, depending on the type of the target application. Self-configuration means the capacity of an algorithm to adjust its operational parameters according to the design requirements. For instance, whenever a given energy value is reached, a sensor node may reduce its transmission rate. Self-organization means the capacity of an algorithm to autonomously adapt to changes resulted from external interventions, such as topological changes (due to failures, mobility, or node inclusion) or reaction to a detected event, without the influence of a centralized entity.

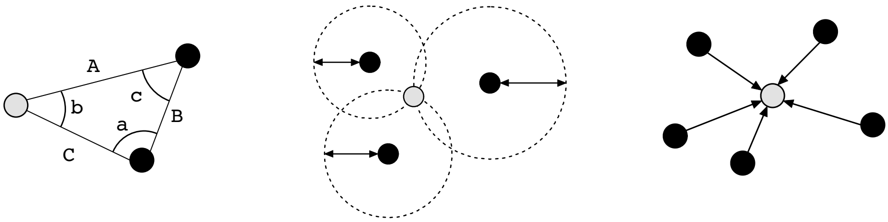
1.2 WIRELESS SENSOR NETWORKS: AN ALGORITHMIC PERSPECTIVE

In the following, we present an overview of some algorithms for basic services (that can be used by other algorithms), data communication, management functions, applications, and data fusion.

1.2.1 Basic Services

Some of the basic services that can be employed by other algorithms in wireless sensor networks are localization, node placement, and density control.

Localization. The location problem consists in finding the geographic location of the nodes in a WSN, which can be computed by a central unit [2] or by sensor nodes in a distributed manner [3–8]. Essentially, the location discovery can be split in two stages: distance estimation and location computation [4]. Usually, the distance between two



(a) (b) (c)

Figure 1.1. Position estimation methods: (a) triangulation, (b) trilateration, and (c) multilateration. (Adapted from reference 10.)

nodes is estimated based on different methods, such as Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), and Time Difference of Arrival (TDoA) [4]. Once the distance is estimated, at least three methods can be used to compute the node location: triangulation, trilateration, and multilateration [9], as depicted in Figure 1.1. Another method to estimate the node location is called the Angle of Arrival (AoA), which uses the angle in which the received signal arrives and the distance between the sender and receiver.

Solutions for finding the nodes' location are often based on localized algorithms in the sense that every node is usually able to estimate its position. For instance, Sichitiu and Ramadurai [11] use the Bayesian inference to process information from a mobile beacon and determine the most likely geographical location (and region) of each node, instead of finding a unique point for each node location. The Directed Position Estimation (DPE) [8] is a recursive localization algorithm in which a node uses only two references to estimate its location. This approach leads to a localization system that can work in a low-density sensor network. Besides, the controlled way in which the recursion occurs leads to a system with smaller and predictable errors. Liu et al. [12] propose a robust and interactive Least-Squares method for node localization in which, at each iteration, nodes are localized by using a least-squares-based algorithm that explicitly considers noisy measurements.

Node Placement. In some applications, instead of throwing the sensor nodes on the environment (e.g., by airplane), they can be strategically placed in the sensor field according to a priori planning. In this approach, there is no need to discover the nodes' location. However, good planning depends on the knowledge of the terrain and the environmental particularities that might interfere in the operation of the sensor nodes and the quality of the gathered data.

The node placement problem has been addressed using different approaches [13–15]. However, current solutions are basically concerned with assuring spatial coverage while minimizing the energy cost. The SPRING algorithm is a node placement algorithm that also performs information fusion. In SPRING it is possible to migrate the fusion role.

Besides spatial coverage [13, 15], other aspects should be considered in a node placement algorithm, such as node diversity [14] and the fusion performance. When

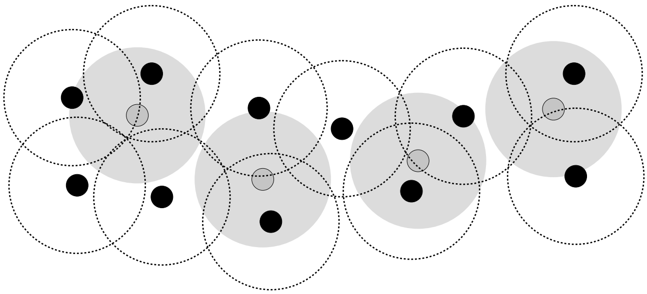


Figure 1.2. An example of node scheduling: Gray nodes are asleep and black nodes are awake.

nodes perform data fusion, an improper node placement may lead to the degradation of information fusion as illustrated by Hegazy and Vachtsevanos [16].

Density Control. The main node scheduling objective is to save energy using a density control algorithm [17–20]. Such algorithms manage the network density by determining when each node will be operable (awake) and when it will be inoperable (asleep). Figure 1.2 depicts an example of the result of a node scheduling algorithm in which gray nodes are asleep because their sensing areas are already covered by awaken nodes (in black).

Density control is an inherently localized algorithm where each node assesses its vicinity to decide whether or not it will be turned on. Some of the node scheduling algorithms, such as GAF [17], SPAN [19], and STEM [18], consider only the communication range to choose whether or not a node will be awake. Therefore, it is possible that some regions remain uncovered, and the application may not detect an event. Other solutions, such as PEAS [20], try to preserve the coverage. However, none of the current node scheduling algorithms consider the information fusion accuracy. As a result, nodes that are important to information fusion might be turned off. A key issue regarding density control algorithms is the integration with other functions such as data routing. Siqueira et al. [21] propose two ways of integrating density control and data routing: synchronizing both algorithms or redesigning an integrated algorithm.

1.2.2 Data Communication

In wireless sensor networks, the problem of data communication is mainly related to medium access control, routing, and transport protocols.

MAC Protocols. The link or medium access control (MAC) layer controls the node access to the communication medium by means of techniques such as contention [22, 23] and time division [24, 25]. Basically, the MAC layer must manage the communication channels available for the node, thereby avoiding collisions and errors in the communication.

Most solutions try to provide a reliable and energy-efficient solution. In this direction, Ci et al. [26] use prediction techniques to foresee the best frame size to reduce the packet size and save energy. To avoid transmitting packets under unreliable conditions, Polastre et al. [23] apply filter techniques to estimate ambient noise and determine whether the channel is clear for transmission. Liang and Ren [27] propose a MAC protocol based on a fuzzy logic rescheduling scheme that improves existing energy-efficient protocols. Their input variables are the ratios of nodes that (i) have an overflowed buffer, (ii) have a high failing transmission rate, and (iii) are experiencing an unsuccessful transmission.

Routing Protocols. Routing is the process of sending a data packet from a given source to a given destination, possibly using intermediate nodes to reach the final entity. This is the so-called unicast communication. In WSNs, data communication, from the point of view of the communicating entities, can be divided into three cases: from sensor nodes to a monitoring node, among neighbor nodes, and from a monitoring node to sensor nodes. Data communication from sensor nodes to a monitoring node is used to send the sensed data collected by the sensors to a monitoring application. This class includes most of the routing protocols proposed in the literature [28]. Data communication among neighbor nodes often happens when some kind of cooperation among nodes is needed. Data communication from a monitoring node to a set of sensor nodes is often used to disseminate a piece of information that is important to those nodes. Based on an efficient dissemination algorithm, a monitoring node can perform different activities, such as to change the operational mode of part or the entire WSN, broadcast a new interest to the network, activate/deactivate one or more sensor nodes, and send queries to the network.

The routing algorithms for wireless sensor networks can be broadly divided into three types: flat-based routing, hierarchical-based routing, and adaptive-based routing. Flat-based routing assumes that all sensor nodes perform the same role. On the other hand, nodes in hierarchical-based routing have different roles in the network, which can be static or dynamic. Adaptive routing changes its behavior according to different application and network conditions such as available energy resources. These routing protocols can be further classified into multipath-based, query-based, or negotiation-based routing techniques depending on the protocol operation.

A natural routing scheme for flat networks is the formation of routing trees. Krishnamachari et al. [29] provide analytical bounds on the energy costs and savings that can be obtained with data aggregation using tree topologies. Zhou and Krishnamachari [30] evaluate the tree topology with four different parent selection strategies (earliest-first, randomized, nearest-first, and weighted-randomized) based on the metrics, such as node degree, robustness, channel quality, data aggregation, and latency. Tian and Georganas [31] identify drawbacks of pure single-path and multipath routing schemes in terms of packet delivery and energy consumption. The InFRA algorithm [32] builds a routing tree by establishing a hybrid network organization in which source nodes are organized into clusters and the cluster-to-sink communication occurs in a multihop fashion. The resulting topology is a distributed heuristic to the Steiner tree problem.

For the hierarchical topology, several algorithms are provided in the literature. LEACH [33] is a cluster-based protocol that randomly rotates the cluster heads to evenly distribute the energy load among the sensors in the network. PEGASIS [34] is an improvement of LEACH in which sensors form chains, and each node communicates only with a close neighbor and takes turns to transmit messages to the sink node.

The Directed Diffusion [35] is a pioneer protocol that tries to find the best paths from sources to sink nodes that might receive data from multiple paths with different data delivery frequencies. If the best path fails, another path with lower data delivery frequency assures the data delivery. Ganesan et al. [36] propose a routing solution, which evolved from Directed Diffusion, that tries to discover and maintain alternative paths, connecting sources to sinks, to make the network more fault-tolerant.

Niculescu and Nath [37] propose the Trajectory-Based Forwarding (TBF) algorithm, a data dissemination technique in which packets are disseminated from a monitoring node to a set of nodes along a predefined curve. Machado et al. [38] extend TBF with the information provided by the energy map [39] of a sensor network to determine routes in a dynamic fashion.

In WSNs, routing protocols are closely related to information fusion because it addresses the problem of delivering the sensed information to the sink node, and it is natural to think of performing the fusion while the pieces of data become available. However, the way information is fused depends on the network organization, which directly affects how the role can be assigned. Hierarchical networks are organized into clusters where each node responds only to its respective cluster-head, which might perform special operations such as data fusion/aggregation. In flat networks, communication is performed hop-by-hop and every node may be functionally equivalent.

Transport Protocols. In general, transport protocols are concerned with the provision of a reliable communication service for the application layer. This is the main objective of the Pump Slowly, Fetch Quickly (PSFQ) protocol [40]. PSFQ is an adaptive protocol that makes local error correction using hop-by-hop acknowledgement. In this case, the adaptation means that under low failure rates, the communication is similar to a simple forward, and when failures are frequent, it presents a store-and-forward scheme. Another transport protocol that aims to provide a reliable communication is the Reliable Data Transport in Sensor Networks (RMST) [41] that also implements a hop-by-hop acknowledgment. However, RMST is designed to operate in conjunction with Directed Diffusion.

An interesting approach is introduced by the Event-to-Sink Reliable Transfer (ESRT) protocol [42, 43]. This protocol is designed for event-based sensor networks, and it changes the focus of traditional transport protocols. The authors state that for WSNs a transport protocol should be reliable regarding the event detection task. ESRT assumes that an event must be detected when the sink node receives a minimum number of event reports from sensor nodes. If this threshold is not achieved, the sink node does not recognize the event. Thus, ESRT adjusts the transmission rate of each node in such a way that the desired threshold is achieved and the event is reliably detected.

1.2.3 Management Functions

In the following, we present some high-level management functions that can be used by different monitoring applications in a WSN. We start by presenting a management architecture, followed by a discussion of data storage, network health, coverage and exposure, and security.

Architecture. A WSN management architecture can be used to reason about the different dimensions present in the sensor network. In this direction, the MANNA architecture [44] was proposed to provide a management solution to different WSN applications. It provides a separation between both sets of functionalities (i.e., application and management), making integration of organizational, administrative, and maintenance activities possible for this kind of network. The approach used in the MANNA architecture works with each functional area, as well as each management level, and proposes the new abstraction level of WSN functionalities (configuration, sensing, processing, communication, and maintenance) presented earlier. As a result, it provides a list of management services and functions that are independent of the technology adopted.

Data Storage. Data storage is closely related to the routing (data retrieval) strategy. In the Cougar database system [45], stored data are represented as relations whereas sensor data are represented as time series. A query formulated over a sensor network specifies a persistent view, which is valid during a given period [46]. Shenker et al. [47] introduce the concept of data-centric storage, which is also explored by Ratnasamy et al. [48] and Ghose et al. [49]. In this approach, relevant data is labeled (named) and stored by the sensor nodes. Data with the same name are stored by the same sensor node. Queries for data with a particular name are sent directly to the node storing that named data, avoiding the flooding of interests or queries.

Network Health. An important issue underlying WSNs is the monitoring of the network itself; that is, the sink node needs to be aware of the health of all the sensors. Jaikaeo et al. [50] define diagnosis as the process of monitoring the state of a sensor network and figuring out the problematic nodes. This is a management activity that assesses the network health—that is, how well the network elements and the resources are being applied.

Managing individual nodes in a large-scale WSN may result in a response implosion problem that happens when a high number of replies are triggered by diagnostic queries. Jaikaeo et al. [50] suggest the use of three operations, built on the top of the SINA architecture [51], to overcome the implosion problem: sampling, self-orchestrated, and diffused computation. In a sampling operation, information from each node is sent to the manager without intermediate processing. To avoid the implosion problem, each node decides whether or not it will send its information based on a probability assigned by the manager (based on the node density). In a self-orchestrated operation, each node schedules its replies. This approach introduces some delay, but reduces the collision chances. In a diffused computation, mobile scripts are used (enabled by the SINA architecture) to assign diagnosis logic to sensor nodes so they know how to perform information fusion and route the result to the manager. Although diffused computation optimizes bandwidth use, it introduces greater delay and the resultant information is less accurate. The three operations provide different levels of granularity and delay; therefore they should be used in different stages: Diffused computation and self-orchestrated operations should be continuously performed to identify problems, and sampling should be used to identify problematic elements.

Hsin and Liu [52] propose a two-phase timeout system to monitor the node liveliness. In the first phase, if a node A receives no message from a neighbor D in a given period of time (monitoring time), A assumes that D is dead, entering in the second phase. Once in the second phase, during another period of time (query time), A queries its neighbors about D; if any neighbor claims that D is alive, then A assumes it was a false alarm and discards this event. Otherwise, if A does not hear anything before the query time expires, it assumes that D is really dead, triggering an alarm. This monitoring algorithm can be seen as a simple information fusion method for liveliness detection where the operator (fuser) is a logical OR with n inputs such as input i is true if neighbor i considers that D is alive and false otherwise.

Zhao et al. [53] propose a three-level health monitoring architecture for WSN. The first level includes the *digests* that are aggregates of some network property, like minimum residual energy. The second comprises the network *scans*, a sort of feature map that represents abstracted views of resource utilization within a section of the (or entire) network [54]. Finally, the third is composed by *node dumps* that provide detailed node states over the network for diagnosis. In this architecture, digests should be continuously computed in background and piggybacked in a neighbor-to-neighbor communication. Once an anomaly is detected in the digests, a network scan may be collected to identify the problematic sections in the network. Finally, dumps of problematic sections can be requested to identify what is the problem. The information granularity increases from digests to dumps, and the finer the granularity, the greater the cost. Therefore, network scans and, especially, dumps should be carefully used.

An energy map is the information about the amount of energy available at each part of the network. Due to the importance of energy-efficiency solutions for WSNs, the energy map can be useful to prolong the network lifetime and be applied to different network activities in order to make a better use of the energy reserves. Thus, the cost of obtaining the energy map can be amortized among different network applications, and neither of them has to pay exclusively for this information itself. The energy map can be constructed using a naive approach, in which each node sends periodically only its available energy to the monitoring node. However, this approach would spend so much energy, due to communication, that probably the utility of the energy information would not compensate the amount of energy spent in this process.

Zhao et al. [55] propose a more interesting solution that obtains the energy map using an aggregation based approach. Mini et al. [39] propose another efficient solution, based on a Markov Chain mechanism, to predict the energy consumption of a sensor node in order to construct the energy map.

Coverage and Exposure. Coverage (spatial) comprises the problem of determining the area covered by the sensors in the network [13, 14, 56, 57]. Coverage allows the identification of regions that can be properly monitored and regions that cannot. This information associated with the energy map [54] can be used to schedule sensor nodes to optimize the network lifetime without compromising the quality of the gathered information.

Azzedine Boukerche [57] defines coverage in terms of the best case (regions of high observability) and the worst case (regions of low observability), and it is computed in a centralized fashion by means of geometric structures (Delaunay triangulation and Voronoi diagram) and algorithms for graph searching. Li et al. [56] extend this work considering a sensing model in which the sensor accuracy is inversely proportional to the distance to the sensed event, and they provide distributed algorithms to compute the best case of coverage and the path of greater observability. Chakrabarty et al. [14] compare coverage to the Art Gallery Problem (AGP), which consists in finding the smallest number of guards to monitor the entire art gallery. Dhillon et al. [13] consider coverage as the lowest detection probability of an event by any sensor. Exposure is closely related with coverage and it specifies how well an object, moving arbitrarily, can be observed by the WSN over a period of time [58].

Security. Security is an issue of major concern in WSNs, especially in surveillance applications, with implication to other functions. For instance, despite the fact that data fusion can reduce communication, fusing data packets makes security assurance more complex. The reason is that intermediate nodes can modify, forge, or drop data packets. In addition, source-to-sink data encryption may not be desirable because the intermediate nodes need to understand the data to perform data fusion.

Hu and Evans [59] present a protocol to provide secure aggregation for flat WSNs that is resilient to intruder devices and single device key compromises, but their protocol may become vulnerable when a parent and a child node are compromised. The Energy-efficient and Secure Pattern-based Data Aggregation protocol (ESPDA) [60] is a secure protocol for hierarchical sensor networks that does not require the encrypted data to be decrypted by cluster heads to perform data aggregation. In ESPDA, the cluster head first requests nodes to send the corresponding pattern code for the sensed data. If the same pattern code is sent to the cluster head by different nodes, then only one of them is allowed to send its data. The pattern code is generated based on a seed provided by the cluster head. No special fusion method is actually applied in the ESPDA protocol, which simply avoids the transmission of redundant data, so any information fusion must be performed by the sensor nodes, not the cluster head. Secure Information Aggregation in Sensor Networks (SIA) [61] presents a fuse–commit–prove approach in which fuser nodes need to prove that they perform fusion tasks correctly. To avoid cheating by fuser nodes, SIA adopts cryptographic techniques of commitments and provides random sampling mechanisms and interactive proofs to allow the user to verify the data given by fuser nodes, even when the fuser nodes or some sensor nodes are corrupted.

1.2.4 Applications

Two of the most basic applications for wireless sensor networks are query processing, and event and target tracking. The former is often used to answer queries posed by users outside of the network, and the latter is used to know about events happening inside the network, including specific targets. These two applications can actually be seen as *application protocols* that might be present in different monitoring applications.

Query Processing. Different solutions explore the query approach using in-network processing to filter and/or aggregate the data during the routing process. Directed Diffusion [35] introduces the concept of interests to specify which data will be delivered through a publish/subscribe scheme, but no query language is specified.

Another possibility is to model the sensor network as a database so data access is performed by declarative queries. The DataSpace Project [62] provides a means of geographically querying, monitoring, and controlling the network devices that encapsulate data. DataSpace provides network primitives to assure that only relevant devices are contacted when a query is evaluated. Sensor Information Networking Architecture (SINA) [51] is a cluster-based architecture that abstracts a WSN as a dense collection of distributed objects where users access information through declarative queries and execute tasks through programming scripts. The Cougar Project [45] handles the network as a distributed database in which each piece of data is locally stored in a sensor node and data are retrieved by performing aggregation along a query tree. Temporal coherency-aware in-Network Aggregation (TiNA) [63] uses temporal coherency tolerances to reduce the communication load and improve quality of data when not all sensor readings can be propagated within a given time constraint. The ACtive QUery forwarding In sensoR nEtworks (ACQUIRE) [64] system considers the query as an active entity that is forwarded through the network searching for a solution. In ACQUIRE, intermediate nodes, handling the active query, partially evaluate the queries by using information from nodes within d hops. Once the query is fully evaluated, a response is sent toward the querying node. TinyDB [65] provides a simple query language to specify the data of interest.

Event and Target Tracking. Event (target) tracking is one of the most popular applications of sensor systems in general. The problem consists in predicting where an event or target being detected is moving to. This is essentially a data fusion application.

Coates [66] uses filters for target tracking in cluster-based networks in which cluster heads perform computations and share information, and the other cluster members sense the environment. To track multiple targets, Sheng et al. [67] use filters that run on uncorrelated sensor cliques that are dynamically organized based on target trajectories. Vercauteren et al. [68] propose a collaborative solution for jointly tracking several targets and classifying them according to their motion pattern. Schmitt et al. [69] propose a collaborative algorithm to find the location of mobile robots in a known environment and track moving objects.

1.2.5 Data Fusion

Data fusion algorithms [70] are orthogonal to the above-mentioned problems, in the sense that these algorithms can be applied to any solution that needs to make inferences or improve estimates.

Classical data fusion techniques have been used to assist solving many problems. For instance, the Least-Squares method has been used to predict sensor data [71] and find nodes' locations [8, 12]; the moving average filter has been used to estimate link connectivity statistics [72], estimate data traffic [73] and the number of events [74], and track targets [75]; the Kalman filter has been applied to refine location and distance estimates [6, 76], track different targets [77], predict the best frame size for MAC protocols [26], and predict sensor data to reduce communication [78].

As discussed in the following, data fusion can have an important role when we design an integrated solution for a wireless sensor network.

1.3 CHALLENGE: SYNTHESIS PROCESS

One of the most important challenges in the design of wireless sensor networks is to deal with the dynamics of such networks. The physical world where the sensors are embedded is dynamic. Over time, the operating conditions and the associate tasks to be performed by the sensors can change. Some of the causes that might trigger these changes are the events occurring in the network, amount of resources available at nodes (particularly energy), and reconfiguration of nodes. Furthermore, it is important that sensors adapt themselves to the environment since manual configuration may be unfeasible or even impossible. In summary, the kind of distributed system we are dealing with calls for an entire new class of algorithms for large-scale, highly dynamic, and unattend WSN.

The complete design of a wireless sensor network, considering a particular application, should take into account many different aspects such as application goals, traffic pattern, sensor node capability and availability, expected network lifetime, access to the monitoring area, node replacement, environment characteristics, and cost. Given a particular monitoring application, the network designer should clearly identify its main goals and the corresponding QoS parameters. For instance, given a fire detection application for a rain forest, we would like to guarantee that the network will operate for the expected lifetime. However, as soon as a fire spot is detected, this information should reach the sink node as fast and reliable as possible, probably not worrying about the energy expenditure of the nodes involved in this communication.

Power-efficient communication paradigms for a given application should consider both routing and media access algorithms. The routing algorithms must be tailored for efficient network communication while maintaining connectivity when required to source or relay packets. In this case, the research challenge of the routing problem is to find a power-efficient method for scheduling the nodes such that a multihop path may be used to relay the data. But, when we consider the particular aspects of the monitoring application, we could apply, for instance, information fusion and density control algorithms to reduce the amount of data packets to be relayed and sensor nodes that need to be active, respectively.

As the sensor network starts to operate, it may be necessary to adjust the functionality of individual nodes. This refinement can take several different forms. Scalar parameters, like duty cycle or sampling rates, may be adjusted using self-configuration and self-organization algorithms. This process may occur in different ways along the operation of the network lifetime.

Ideally, a WSN designer should come up with both the hardware and software necessary to accomplish the aspects mentioned above. Unfortunately, it seems that we are far from this scenario. We are still giving the first steps in the design process of a wireless sensor network as we move toward to a more disciplined development. Most of the studies found in the literature study particular problems for a WSN. That is possibly the way we should go since we need to have more experience before we can design a complete solution in a more systematic and automated way.

Figure 1.3 depicts a possible monitoring application for a rain forest. In this case, we might be interested in detecting different events such as the presence of a rare bird, a fire spot, and different environmental variables. The operation of the sensor

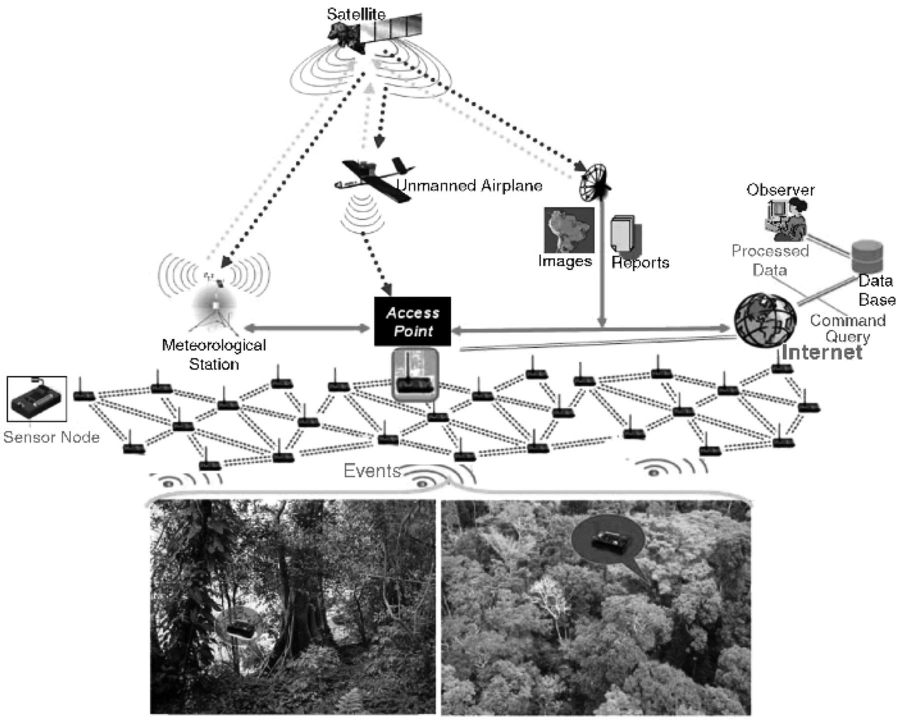


Figure 1.3. Monitoring application for a rain forest.

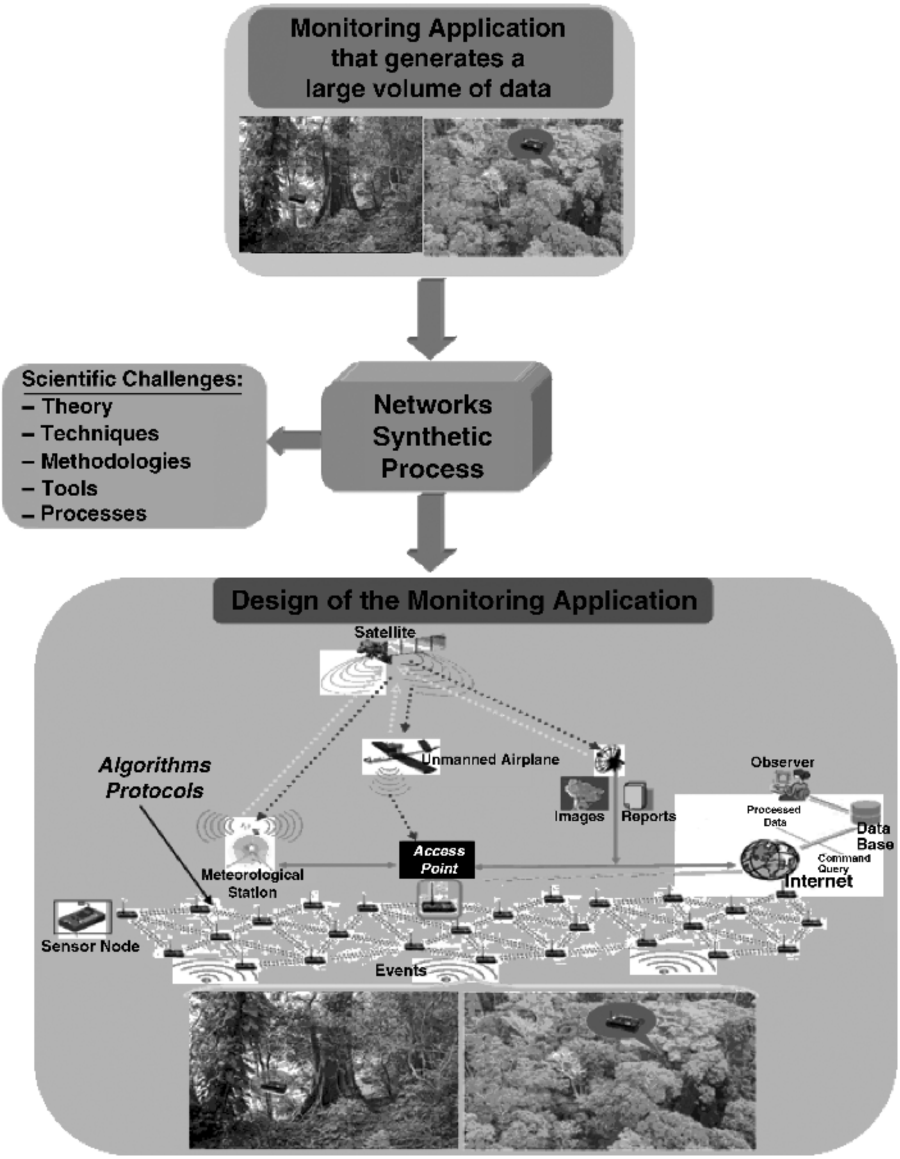


Figure 1.4. Synthesis process.

network can also be based on data received from a meteorological station, an unmanned airplane, or a satellite. Thus, given the different application requirements and data sources, what are the best algorithms and sensor nodes that should be used to accomplish the desired goals? This is a research challenge that we are starting to face once more, and more real monitoring applications are being deployed. Notice that we can even go one step further and build a specific hardware node that best fits to the proposed solution, leading to a truly hardware–software codesign.

In order to achieve this proposed solution, we need a network synthesis process, as depicted in Figure 1.4. This is similar to what happens currently in the design of an integrated circuit (IC) that starts with its high-level specification and finishes with its physical design. The synthesis process is guided by some aspects such as the testability of the IC. It is important to design a more testable IC, since a chip is tested not to check its logical correctness but to check its manufacturing process. In the case of the WSN synthesis process, there are very interesting scientific challenges that we need to overcome to have this automated development, as it happens in the synthesis of an integrated circuits.

These challenges are related to the theory, techniques, methodologies, tools, and processes. We need to propose new fundamental principles that will create a theory to synthesize both the hardware and software of a wireless sensor network. This theory will lead to techniques, methodologies, tools, and processes that will enable designers to design new sensor networks for different monitoring applications in a systematic way. In this vision, algorithms for wireless sensor networks have a fundamental role, since they will be the outcome of this synthesis process.

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