A Technical Report:
Wireless Sensor Networks and How They Work

Prepared for
Ann Holms
University of California Santa Barbara

Prepared by
Ethan Culler-Mayeno
University of California Santa Barbara
Abstract

Wireless sensor networks are a budding technology with the potential to change the way that we live. This report explains the workings of each network as a system of tiny computers called motes and the parts of the network. Furthermore, this report goes on to explain the parts of each mote, including a portion on MEMS technology to show the development of motes.
# Table of Contents

Introduction........................................................................................................1
WSNs: How do motes make up a system? ..........................................................1
   How do motes communicate with each other? ...........................................2
   What safety mechanisms are in place? .....................................................3
   How do WSNs communicate with the user? ..........................................3
Parts of a Mote...................................................................................................4
   Sensors ...................................................................................................4
   Power Source .......................................................................................4
   Radio .....................................................................................................5
   Electronic Brain ...................................................................................5
   Mote Base .............................................................................................5
Mote: Theory of Operation ................................................................................5
MEMS Technology............................................................................................6
   What Is MEMS?.....................................................................................6
   How Is MEMS Used In Motes..............................................................7
Conclusion .........................................................................................................8
References..........................................................................................................9

# List of Figures

Figure 1: An Illustration of a Wireless Sensor Network.................................2
Figure 2: The parts of a mote, illustrated.......................................................4
Figure 3: Order of Operations in mote data collection ..................................6
Figure 4: MEMS size comparison .................................................................7
Introduction

Wireless technology has expanded the limits of our world. Through this innovation, people have been given freedom to work away from their desks or even outside. The newfound freedom that people are beginning to enjoy with their computers has started making the world of technology and nature blend. Wireless Sensor Networks are the next stage of this technology-nature cohesion. Although a young technology, the applications have been varied and promise to be even more varied. These networks are collections of small devices, known as motes, with limited computational power. Each mote has approximately 1-100th of the computing power of a PDA, but when combined with hundreds of other motes, they combine to form an extremely capable system.

Wireless Sensor Networks, or WSNs, have been used to enable better data collection in scientific studies, create more effective strategic military defenses, pinpoint the origin of a gunshot, and monitor factory machinery [Culler, 2004]. All of these uses depend on the ability to collect data such as light, vibration, moisture, temperature, and more, as well as the ability to communicate with each other. This last ability is what makes a collection of motes so much more powerful than any mote in particular.

The purpose of this report is to explain how wireless sensor networks work, including the workings for each individual mote. The way the multi-function chips are made, as well as the communication system will be discussed. Specialized motes will not be discussed, as multifunction motes are more appropriate for this report. Past uses and potential applications will be touched upon briefly to further illustrate the faculty of these machines. The introduction of these collections of computing devices has brought forth changes in factory safety, machine maintenance, data collection, and military effectiveness [Culler, 2004].

Section one describes how motes communicate with each other, the way they collect data, and the way they transfer data to a computer. The following section will discuss the capabilities and structure of an individual mote. The next section contains information about the chips used in the motes, including information about Micro-Electronic Mechanical Systems, MEMS, and how that applies to this field. Finally, to bring the paper to a close, I will review the basics of WSNs and talk more about their future.

WSNs: How do motes make up a system?

Wireless Sensor Networks are collections of motes. Motes are the individual computers that work together to form networks. The requirements for motes are extensive. They must be small, energy efficient, multifunctional, and wireless. Collections of motes communicate with each other to reach a common goal. For example, if the goal is to collect information about the microclimates around all sections of redwoods in a forest, the motes are placed in the trees to form a network. Once placed, they collect and transmit data to each other, and eventually to a main computer.
Due to interference from the surroundings and the mote’s maximum broadcast range, not all of the motes placed around trees can communicate with all others. The mote’s radios are designed to save as much power as possible and therefore have a limited broadcast range. This range is approximately 30 meters [Culler, 2006]. If the motes have a short radio broadcast range, and many motes are more than 30 meters off the ground, how can one collect data from the motes farthest away from the computer (or station)? Motes solve this problem by packaging their information and broadcasting it to multiple other motes, which then communicate with others, to find the most rapid or successful route for the information to travel to reach the main computer located elsewhere.

**How do motes communicate with each other?**

Motes communicate with each other using radio transmitters and receivers. They form networks with other motes that change with the positions of the motes. They create links with each other in different configurations to maximize the performance for each mote. These links all lead to the “parent” mote, which transmits the information from each of the “child” motes to whatever computer or PDA type device is used to collect and process the data. Figure 1 illustrates one possible path data can travel between the outer motes and those close to the computer/station.

![Figure 1. The Motes 1 through 13 are the children motes (all the ones in light grey), Mote 14 is the parent (in purple). The “Computer” (in red) can be any type of computer such as PDA, laptop, etc. as long as it is capable of accessing the internet via a specified ISP (the grey building with yellow windows). The arrows connecting the motes are not fixed, and to illustrate this, they are purposefully unorganized.](image-url)
When the motes are linked together, they form parts of a machine with greater computational power than any of the individual parts. These “machines” of motes change with position and with conditions. Sometimes high moisture and other situations can affect broadcast abilities of many motes. Changes in conditions can make some connections stronger than they used to be, and others nearly impossible. The thinking capability within the network allows the pieces to reorganize in such a way that all motes will continue to be functional [Computer, 2001].

**What safety mechanisms are in place?**

In addition to communicating, motes also adapt to their situation. In the case of a malfunction the remaining motes will reconfigure the network. For example, there are 500 motes in place around a system. If 20% or 100 motes die, the rest of the motes will reconfigure the network to continue working with the remaining 400. Furthermore, 400 motes will collect as much data as 400 scientists working non-stop for that period of time.

The bigger problems that face these networks are people with destructive intentions, and the potential for motes to keep “working” while spitting out bad information. Corrupt data can sometimes be caught when the information is used and reread by humans, but the times that it goes unnoticed can slightly or significantly alter conclusions drawn from the data.

The threat of hackers is a serious problem because the operating system for the motes is an “open-source” system, which allows relatively easy access to codes. Some security systems are in place currently, such as code recognition software imbedded in the operating systems. All security procedures will develop with the growth of the technology in response to a larger number of hackers. The harder people try to break the system, the more the system will be protected [Culler, 2004].

**How do WSNs communicate with the user?**

Wireless sensor networks communicate within themselves as well as with a user not necessarily near the network’s location. How does this work? Wireless sensor networks collect data about what is happening, and perform some action according to that data, be it moving, setting off alarms, or simply recording the data. All of these actions change the world that the mote is in, causing other changes, and so on. Because of the connection between the motes, all of these changes affect each mote, and all of the data collected by the mote is routed to the parent mote. This parent mote is connected to a computer of higher power that performs a function for which the motes are not designed. One such function is to access the internet and transfer the motes’ data to the user’s computer. The user may also communicate with the motes. If the user gives some directives, the directives will be sent over the internet to the computer/station. The computer/station will communicate the same directives to the parent mote, which then disperses the message amongst its “children” [Estrin, 2005].
Parts of a Mote

Motes, the individual computers that make up a Wireless Sensor Network, are very small and simple. While we associate a computer with a PC, the technical definition of a computer is a thing that computes, be it human or machine, thus motes are computers.

Most motes consist of five crucial components. These components include a number of sensors, such as temperature, moisture, and vibration sensors, a power source, in the case of older motes, 2 AA batteries, a radio transmitter/receiver, and an electric “brain.” (Figure 2) [Culler, 2006]

Figure 2. This figure illustrates the construction of a first generation mote, usually known as a Mica-mote.

**Sensors:** When motes are under construction, their intended purpose often dictates the sensors that are added to the mote. The mote in Figure 2 contains three types of sensors: temperature, moisture, and vibration. This is a fairly typical mote, but some motes have many more functions. There are motes that take photographs of the surroundings, sense motion, measure light intensity, and much more. The sensors are attached to the mote base and communicate readings to the electronic brain.

**Power Source:** The power source for the mote also depends on the mote’s intended use. If the mote is designed to last a very long time, say one year, it will have a larger power source than a mote that is only meant to run for a month. The power sources usually range between a couple of AA batteries, and a watch battery, but with the new smart-dust motes, also called “Spec,” they can collect enough energy to sustain themselves from ambient light, or even vibrations. The power source is connected to the mote base and provides the energy required to run the sensors, electronic brain, and radio.
**Radio:** The radio consists of a radio transmitter and a radio receiver. Both of these parts must exist for any mote to fully communicate with the other motes. The radio, when transmitting, receives information from the electronic brain and broadcasts the data to other motes according to the network connections. In the other direction, when receiving, the radio receives information from another mote’s radio and transmits it to the electronic brain. The radio is connected to the mote base.

**The Electronic Brain:** The older motes’ brains consist of a microprocessor and some flash memory. Many of them have connectors to add other processes and sensors with ease. The MEMS motes also contain an analog-digital converter. The basic functions of the electronic brain are to make decisions and deal with collected data. The electronic brain stores collected data in its memory until enough information has been collected. Once this point is reached, the microprocessor portion of the electronic brain then puts the data in “envelopes,” or packages of data formatted for greatest transferring efficiency. These envelopes are then sent to the radio for broadcast. The brain also communicates with other motes to maintain the most effective network in much the same way it deals with data. The electronic brain is connected to the base and interacts with the sensors and radio.

**Mote base:** The mote base is simply the base on which the mote is built. In the case of MEMS motes, the base is the inactive metal layer in the chip, and in the case of multi-chip motes, the base consists of a circuit board that provides connections between the mote’s pieces.

**Mote: Theory of Operation**

Motes collect and transfer data using four stages: collecting the data, processing the data, packaging the data, and communicated the data. Each mote collects data using its various types of sensors. After collecting the data, the mote processes the data using its electronic brain. Once the data has been processed, the brain packages the data into an easily handled form [Culler, 2004]. This process is known as enveloping. Once the data has been collected and processed to this point, the mote then begins to interact with other motes. This process can be seen in Figure 3. [Computer, 2001]
This process is one of many ways motes differ from traditional computers. Another way is motes spend as much as 99% of their time “sleeping” to conserve energy, only waking up to record data, send and receive information (either data or instructions), or when instructed to by its programming.

**MEMS Technology: The Future of Motes**

Development of Micro-Electric Mechanical Systems, or MEMS, has helped to further the progress of WSNs. MEMS are extremely small chips integrating electrical circuits and mechanical processes to both record and process data in a single chip. This not only saves huge amounts of space, but also cuts down the power usage for each device.

**What Is MEMS?**

MEMS is the integration of electrical devices and mechanical structures at an extremely small scale, usually around one micrometer. These integrated devices are manufactured using three different processes: deposition, lithography, and etching. These manufacturing techniques blend the ability to deposit thin films of material on a substrate, to apply a patterned mask on top of the films by photolithographic imaging, and to etch the films selectively to the mask. [MEMS exchange, 2006]

Deposition, the process that applies thin films of material onto substrates, is done in a number of ways. These include Chemical Vapor Deposition (CVD), Electro-deposition, Epitaxy and thermal oxidation, which all happen due to a chemical reaction, and Physical Vapor Deposition (PVD) and casting, which both depend on physical reactions. The common link between all of these methods of Deposition is that all of them physically deposit the material on the substrate, as there are currently no methods, chemical or otherwise, that form the material on the substrate. [MEMS exchange, 2006]
The next step in MEMS formation is Lithography. Lithography, when referring to MEMS, is usually a transfer of a pattern to a photosensitive material by selective exposure to a radiation source like light. This pattern can either be used to mark where the etching is supposed to happen, or where it is not supposed to happen. These two versions are called additive and subtractive.

The final stage in MEMS construction is the etching, which falls into two different categories, wet and dry. Wet etching consists of the material being dissolved, in the pattern created by the lithography, when immersed in a chemical solution. Dry etching is when the material is sputtered or dissolved using reactive ions or a vapor phase etch-ant. Both of these types of etching cause the material that was placed on the substrate during the deposition step to dissolve according to the pattern produced in the lithography step. [MEMS exchange, 2006]

**How is MEMS used in motes?**

Since MEMS fits the three main requirements for motes quite well, you have your entire mote in one chip. MEMS makes it possible to have many sensors as well as a “brain” capable of analyzing the data the sensors collect, and a radio transmitter all in a chip about 3 millimeters on a side like the “Spec” chip shown in Figure 4. Most of the space older motes use is taken up by the battery and the radio, but with MEMS everything can be incorporated in a single tiny chip.

![Figure 4. Illustration of the size of MEMS chips. This is a chip containing all of the parts of a mote.](MEMS exchange, 2006)
Early motes contained a series of larger chips each with a specific function (Figure 5), but as MEMS progresses, WSNs have incorporated MEMS chips into their devices. These motes are still the most common form due to relative ease and cheapness of manufacturing compared to chips like “Spec.” (Figure 4)

![“Spec”](image)

![“Mica-mote”](image)

Figure 5 Berkeley “Mica” motes contained many parts. This mote could run for more than a year on 2 AA batteries. The dot on the large center chip is “Spec” as seen in Figure 4 [Culler, 2006]

**Conclusion**

WSNs are still uncommon. This is still a young technology, allowing WSNs great growth potential. It is this potential that captures the attention of those who interact with WSNs. The question that is constantly asked is “what new use can we come up with for this?” There have been many answers to this question, including: data collection, strategic mine placement, machinery monitoring, and much more.

The way that Motes are made is a huge part of the success of WSNs in such different situations. Another reason they are successful is the way that the motes work together to form a network. Using MEMS technology, motes have been becoming smaller and more efficient. The uses and capabilities of WSNs are varied, and the only way to fully understand the extent to which they can be adapted will be to wait and see what happens. The future of WSNs is bright, as increasing attention is brought to their uses. Who knows, WSNs may become as commonplace as the PC.
References


