A Review on the Wireless Sensor Networks – Smart Dust

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Abstract*—So-called "Smart Dust" is envisioned to combine sensing, computing, and wireless communication capabilities in an autonomous, dust-grain-sized device. Dense networks of Smart Dust should then be able to unobtrusively monitor real-world processes with unprecedented quality and scale. Smart Dust is an upcoming technology made up of tiny, wireless sensors which are also called MOTES. The devices are smart enough to talk with other sensors which are small to adjust on the head of a pin. These are light in weight that they can be placed in the environment like any ordinary dust particle. A Smart dust is a Millimeter-scale self-contained microelectromechanical sensor (MEMS) devices which include sensors of the ability of computing with bi-directional wireless communications technology and a power supply. The tiny dust particles, smart dust sensors can be spread throughout buildings or into the atmosphere to collect and maintain data.

***IndexTerms*—Smart Dust, MEMS, Power Management.**

I. INTRODUCTION

Smart Dust is commonly used as a synonym for tiny devices that combine sensing, computing, wireless communication capabilities, and autonomous power supply within a volume of only few cubic millimeters at low cost. The small size and low per-device cost allows an unobtrusive deployment of large and dense Smart Dust populations in the physical environment, thus enabling detailed in-situ monitoring of real-world phenomena, while only marginally disturbing the observed physical processes. Smart Dust is envisioned to be used in a wide variety of application domains, including environmental protection (identification and monitoring of pollutions), habitat monitoring (observing the behavior of animals in their natural habitats), and military systems (monitoring activities in inaccessible areas). Due to its tiny size, Smart Dust is expected to enable a number of novel applications. For example, it is anticipated that Smart Dust nodes can be moved by winds or can even remain suspended in air, thus supporting better monitoring of weather conditions, air quality, and many other phenomena. Also, it is hard to detect the bare presence of Smart Dust and it is even harder to get rid of it once deployed, which might be helpful for many sensitive application areas.

The term "Smart Dust" was created by a leading Professor Kristoder Pister, an electrical and computer engineer at the University of California, Berkeley. His idea was for a Micro Electro-Mechanical System (MEMS) that was so small, one could distribute the device, like dust, wherever the situation required and monitor a system or device. Characteristics that are applied in MEMS technology but are not limited to include sensors, bi-directional wireless communication, and solar cells. Figure 1 shows the concept of the MEMS.

There have been significant research studies that all aim toward the same goal of Smart Dust. Topics covered in this paper include a brief overview of Smart Dust or MEMS, obtaining nanostructure MEMS, communication protocols using the mesh network and not a discrete data router, alternatives for testing the sensor network efficiently for proper operation, power studies of a MEMS product and possible lower power alternative operation, and applications of successful implementation of current MEMS technology.

The main application today for MEMS is a cheaper alternative for a network of monitors or sensors for a system. Some examples are networked earthquake sensors, cars equipped with anti-collision sensors, and other maintenance requirements. The military is also invested in Smart Dust for warfare, such as, to track enemy movement.

Current research (cf. [1] for an overview) is mainly focusing on so-called COTS (Commercial Off The Shelf) Dust, early macro prototypes of Smart Dust. COTS Dust nodes such as the Motes [24] developed at UC Berkeley are built from commercially available hardware components and still have a volume of several cubic centimeters. Unfortunately, these devices cannot be simply scaled down to the cubic millimeter size of true Smart Dust. First Smart Dust prototypes [21] demonstrate that the tremendous volume reduction (factor 1000 and more) may require radical changes in the employed technologies (e.g., use of optical instead of radio communication) compared to COTS Dust. These technological changes have important implications for algorithms, protocols, systems, and infrastructure. Our goal is to examine these implications and develop solutions for the resulting problems.

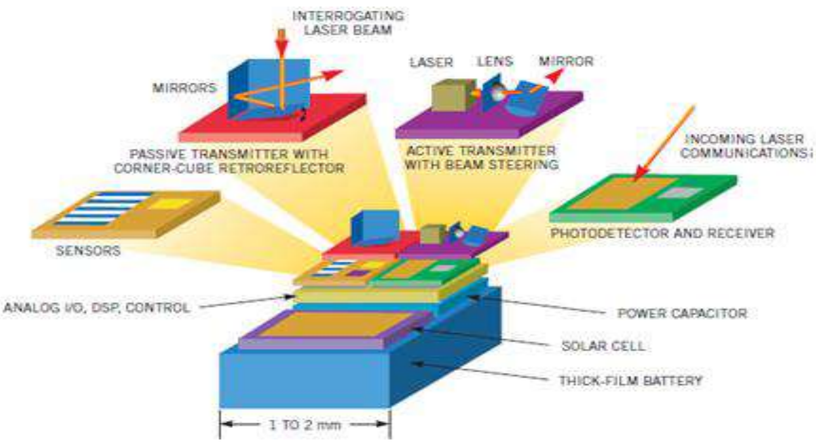

Figure 1: Concept of MEMS

II. Micro Electro-Mechanical Systems

The Smart dust mote structure is shown in Figure 2 single pack of microelectromechanical sensors (MEMS) is a semiconductor laser diode and microelectromechanical beam for active optical transmission. A MEMS corner-cube retro-reflector used for passive optical transmission and an optical receiver for signal processing and is to control circuitry and a power source based on thick-film batteries and solar cells. This package will have the ability to sense and communicate and compute with other sensors that are to be self-powered.

University of California, Berkeley created these motes, as in figure 1, starting off as an off-the-shelf sensor containing a microprocessor, temperature sensor, light sensor, 900 MHz radio, and a battery underneath to power the device. Figure 2 shows the technology available at the time with a 5 by 9 mm MEMS that has options such as vibration, acoustic, magnetic, light, temperature, or proximity –sensor modules. [1] A company, Crossbow, offered this device which started at $895.

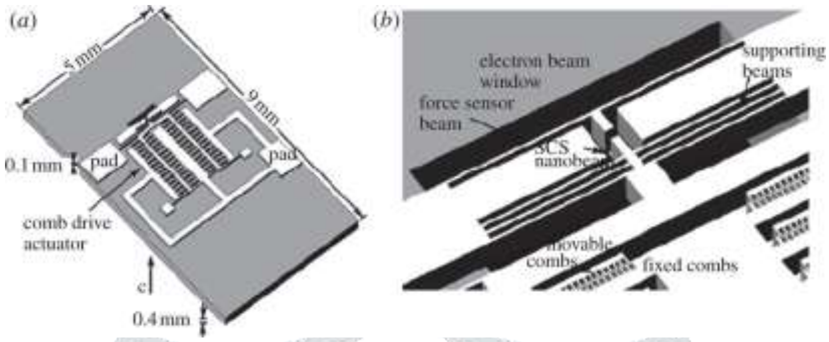

Figure 2: Smart Dust MEMS Architecture

III. Power management strategies in Smart Dust

There are different approaches to reduce the total power consumption in wireless sensor networks. Based on the circuit techniques that can be used to decrease the amount of energy that the network is consuming, one can categorize them as follow:

- Sub-threshold operation: Some of the systems in the University of Michigan use a power supply lower than threshold voltage to reduce the active power consumption by sacrificing performance.
- Asynchronous circuits: SNAP, a processor from Cornell University eliminates the clock power by using asynchronous circuits.
- Power supply gating: In order to deal with the problem of leakage current, transistors can be used to turn off the power supply to those blocks that are not being used. This is done on systems from Harvard University and the University of California, but each use different method to do this.
- General purpose computation: which is based on using processors with load-store or accumulator in the center of the system and as the core processor.
- Event-driven: In this category, network responds only if an event is detected in the environment which need the attention of that network.
- Applications acceleration: Using hardware acceleration in the system will also decrease the power consumption.

IV. Working and Communication methods in Smart Dust

The mote is one of the emerging sensor computing techniques. The mote is a small computer which having low power and low cost. One computer examines one or more sensors. The sensing applications are common to the motes such as to sense temperature, light, sound, position, acceleration, stress, vibration, humidity, etc. The computer connects with radio link to monitor sensors. The radio link transmits the sensing power from 10 feet to 200 feet distance [6]. Because of small size, the motes having normal radios power. The motes run on batteries and some works with power grid in some applications. If the motes are very small to maintain batteries, in such cases it will work on solar power.

One of the most important aspects of the Smart Dust network is the communication between dust nodes. All the motes in the network have to communicate with each other through the base station. While considering all the design constraints due to size and power limitation, data must be collected form the motes simultaneously, sent to base station for further action.

In down-link (i.e. data propagation from base station to the dust motes), base station broadcasts to all the motes in the network at a rate of several kbps. And in uplink (i.e. data propagation from motes to the base station), the data transfer rate is of 1 kbps. Hence, if a total number of 1000 dust motes are employed in the network, the data throughput will be 1 Mbps. The data transfer both in uplink and down-link should support distances of a couple of hundred meters.

There are other specifications regarding the mote. Dust mote size should be less than 1 mm3 and must have a power consumption of at most 1 μW. We also need a secure and reliable transmission method for communication in the network. There are several options possible, but in this thesis work, we will discuss two methods: Radio frequency (RF) and optical communications. Each of them have their own strong and weak points that is discussed and compared in the following section.

Basically, the task of communication system is to send and collect commands to and from motes. We can categorize them into following groups:

- Radio Frequency Transmission
- Optical transmission technique
- Free-space optical communication
- Passive Laser based Communication
- Active Laser based Communication
- Fiber Optic Communication

V. Current MEMS applications

Advanced Sensor Technologies (AST) created a system specific for the irrigation system of golf courses north of Scottsdale, AZ. Using MEMS or Smart Dust used reduced irrigation costs by about 15-20%. The MEMS created by AST for these golf courses was a soil monitoring system. This system monitored moisture of the soil, salinity sensors to monitor the total dissolved solids, residual minerals dissolved in the water after evaporation that can kill the plants, and temperature sensors to monitor the surface of the greens and fairways to measure stress. These 3 sensors were able to ascertain symptoms of certain diseases that can be prevented early on saving time and money with early prevention.

BP started a called Loch Rannoch. The goal was to create a sensor network that can operate under high vibration environment, high metal content surroundings, and high temperatures of about 80°F to 100°F. The final product is a condition monitoring system that can alert when there is a shaft out of true and a machine that is out of balance. Sensors of this system incorporated a tachometer for speed, and as much as six accelerometers to measure the machines vibrations. This reduced their maintenance costs because instead of repairing the machines every X amount of hours, they repaired machines when needed. The U.S. Army used the Crossbow MICA2 MEMS to locate a snipers position. The mote was equipped with an acoustic sensor that could triangulate the location of a firing weapon to within .6m to 1m of average accuracy.

VI. Future applications for smart dust and Limitations

It's nice to have an idea about the future of smart dust. Berkeley Sensor and Actuator Center which has been funded by DARPA, has some future plans and possible applications for smart dust which make it possible to imagine how far we will be able to go using this kind of networking technology. They have already planned some military and also commercial application for smart dust and they have already started to work on. Below some interesting application which BSAC has predicted for smart dust network and started to work on them has been discussed.

One of the possible applications is called "Inventory control". The main idea here is a remote control for the home appliances. It allows the owner to be able to track and control different tools like truck, warehouses and so on remotely while you are away. So one can control the condition and state of each of his/her home appliances whenever and wherever he/she wants to.

The other application for smart dust which can be expected to be implemented in near future is "Smart office spaces". We always have problems setting the air conditioner to the degree appropriate for everyone. This problem gets more serious when lots of people are at the same place like an office. Imagine that you will have some kind of network of sensors which are sewn to your cloths and continuously reports your body condition to a controller, and that in turn controls the air conditioner in your office. Getting the correct input information, air conditioner can run in the way which is proper for at least majority of people in an environment or possibly all of the people at the same place. So you and your office mates can enjoy the proper air condition without having any kind of complaints.

The smart dust technology also can be employed to serve disable people and make their life much easier. One idea about this application comes with a mail from a disable man to Berkeley Sensors and Actuators Center. He suggested that we can design some kind of "quadriplegic mote" and we can somehow put it on a disable face. So this mote can detect and monitor specific face reactions and translate those facial reactions to some commands. These commands can be used to start and control different devices like computer and wheelchair or even a car. This can be a huge step for disables independence.

One of the use case which can be a possibility to fabricate using this technology involves changing the keyboard definition as we have it today to a what which is so called "virtual keyboard". In this hypothesis, scientist think that it will be possible to replace the current keyboards to smart motes on our fingers which will translate our meaningful finger movements, to real action sin our computer. This concept, in general offers a whole new way of connecting to your computers, laptops and all the similar devices. This is a revolutionary concept which will make the life much easier for people with special needs. For example, based on this concept, we shall be able to play a piano without touching an actual physical piano and this shall open up for a whole new world which our imagination can have a free and active role in it.

Limitations

- The Major disadvantage of Smart dust is privacy. This technology notes every small change in the environment, it may harmful to adopt in every situation.
- The limitation is cost. It is still developing technology; because of this the price is comparatively high.
- Sensor nodes are randomly deployed and don't follow any standard rules. The random sensors makes weak for unusual topology. There will be no special maintenance to the sensors once installed.
- There is no special frame work to the sensors. So that it is easy to route every routing algorithm so tracking of the sensors become very easy and it leads to security issues.
- The sensors works on battery power, the availability of the power is limited and difficult to replace battery often.

VII. Conclusions

Smart dust is an emerging technology; many researches are going on to make it available with low price and small size. The cubic millimeter sensing nodes, which are capable of bidirectional communication? The components of the smart dust are to gather and maintain the data. The optical devices to sense the data and electrical equipments to transfer data to adjacent devices. The smart dust mote designing to minimize the power usage and maximize the capability to accesses the data. The use of passive optical communication allows the construction of tiny and energy efficient sensor nodes compared to current radio-based COTS devices. However, it must be emphasized that this mode of communication implies a number of drawbacks. Besides requiring a free line of sight for communication, Smart Dust networks have a single-hop topology, where sensor nodes can only communicate with a base station transceiver. That is, Smart Dust nodes cannot talk to each other directly.

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