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Study of Power Management in Adhoc Networks

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Abstract: ***In wireless communication, idle listening, receiving and transmitting are the main source of consumption of energy. Much research on wireless networks have focused on the power consumption of the wireless nodes, while at the same time how to acquire power from ambient environment is another direction to extend the battery lifetime. Mostly extending the lifetime of WSNs rely on making the electronic circuitry power efficient by incorporating advances in node architecture, transceivers, access protocols and on finite energy sources like batteries. In contrast, WSNs Powered by Ambient Energy Harvesting can also prove to be useful and economical in the long term as they can operate for very long periods of time until hardware failure, because ambient energy can be harvested from the environment perpetually. Although cellular networks account for a rather small share of energy use, lowering their energy consumption appears beneficial from an economical perspective. In the strive for lessening of the environmental impact of the information and communication industry, energy consumption of communication networks has recently received increased attention. According to PSM, each station must announce traffic before its transmission. PSM requires for this purpose a rather large handshaking period to complete the required announcements. This functional behavior puts a heavy constraint on the size of the announcement period and consequently on throughput, delay and more importantly on power consumption. This paper presents a survey on the various power saving techniques used in wireless networking today. The work presented covers topics ranging from the use of energy harvesting techniques at the physical layer to partitioning the load of power hungry computations across multiple devices at the application layer. While research in this area continues to grow, few standards have yet to emerge that incorporate the use of each of these techniques. The types of wireless networks considered include Wireless Local Area Networks (WLANs), Wireless Personal Area Networks (WPANs), and Wireless Sensor Networks. Existing standards for performing power management in each of these networks are discussed, and their effective use is analyzed. The role that these standards play in industry as well as the role played by current research in this area is also introduced.***

Keywords: Power saving Mechanism(PSM), Zigbee, Dynamic Voltage Scaling (DVS), (GaN)Aluminium Gallium nitride, local control centres (LCC)

1. Introduction

Traditionally, systems were wire based, which were essentially extensions of laboratory based Data Acquisition (DAQ) Systems. To overcome the many disadvantages of wired systems, use of wireless technologies have been proposed. They can be cellular networks or WSN. Cellular networks are widely used for mobile communication whereas Wireless Sensor Networks (WSNs) leads to different applications that involve a tight coupling between computing infrastructure and the physical world.

A Cellular network is one of the radio network distributed over land areas called cells, each served by at least one fixed-location transceiver known as a base station .When these cells joined together provide radio coverage over a wide geographic area. Cellular networks provides the advantages such as increased capacity, reduced power use, large coverage area, reduced interference from other signals. In cellular architecture the network is partitioned into a grid of cells to perform fault detection and recovery with minimum energy consumption. The general applications of wireless sensor networks require many wireless sensor nodes to form a network to sense the signal . Extreme events like earthquakes can cause damage to infrastructures. Moreover, the infrastructure may undergo gradual deterioration over the time due to different environmental, physical and chemical factors. However the common problem in both the networks is the source of energy which is most often an attached battery cell. Thus, a wireless system throws up the new problems *being that of power*. Due to the limited capacity of batteries and the difficulty of frequent battery recharging or replacement, energy is a scarce and precious resource. Decreasing the energy consumed during system operation, will directly translates to increased lifetime.

As wireless networks become an integral component of the modern communication infrastructure, energy efficiency becomes an important challenge due to the limited battery life of mobile terminals. Two different operational modes are defined in IEEE802.11 [1], the dominating WLAN technology today: the infrastructure network in which a specific central entity manages communications between stations, and the ad hoc network where spontaneous mobile nodes (we shall use interchangeably the word node or station) communicate with each other over multiple wireless hops [2, 3]. Without proper power management of roaming devices, the energy required to keep wireless devices connected to the network over extended periods of time quickly dissipates. Users are left searching for power outlets rather than network ports. A plethora of power management schemes have been developed in recent years in order to address this problem. Solutions exist at every layer of the traditional network protocol stack, and each of them promises to provide their own level of energy savings. Techniques for decreasing the consumption of energy are necessary to prolong the network life time as much as possible and there are many mechanisms for achieving this task. Most of the energy is consumed in the wireless network interface, so many energy saving mechanisms work in this area. Wireless sensors are generally powered by batteries that give a finite amount of energy. The standard technique is Power Saving Mechanism (PSM) [4]. PSM is used in common wireless networks such as 802.11, 802.16 and 802.15.4. In these networks, the node or sensor is allowed to sleep for a period of time switching its wireless network interface off to conserve energy. A common alternative technique is Power Control (PC) scheme[5,6,7]. This scheme changes the transmit power according to the distance between the transmitter and receiver to reduce the consumption of energy. In addition, PC is also used to improve spatial reuse of the wireless channel. The two techniques (PSM and PC) are most commonly used in conserving energy in wireless ad hoc networks. In this study, the two schemes are combined and implement in IEEE 802.15.4 standard.

This Paper discusses several such emerging techniques that will help achieve the goal of long lasting wireless networks . In this paper techniques for energy-efficient architecture is presented in Section 2. DVS techniques for power management is discussed in Section 3 and RF Transceiver design in Section 4. Section 5 provides a brief overview of WLANs, WPANs, and WSNs, including a discussion of how each type of network differs in terms of their requirements for performing power management. Section 6 talks about the recent advances that have been made in the field of power management, followed by a short description of the products available from industry which take advantage of this research . Finally, Section 7 provides a summary of the entire paper, with references and a list of the abbreviations used throughout the paper following at the end.

2. Power Constrained Wireless Networks

Wireless networks have been a hot topic for many years. Their potential was first realized with the deployment of cellular networks for use with mobile telephones in the late 1970's. Since the deployment of cellular networks and use of mobile telephones, many other wireless wide are networks (WWANs) have begun to emerge, along with the introduction of wireless Metropolitan Area Networks (WMANs), wireless Local Area Network (WLANs), and wireless Personal Area Networks (WPANs). Fig. 1 shows a number of standards that have been developed for each of these types of networks

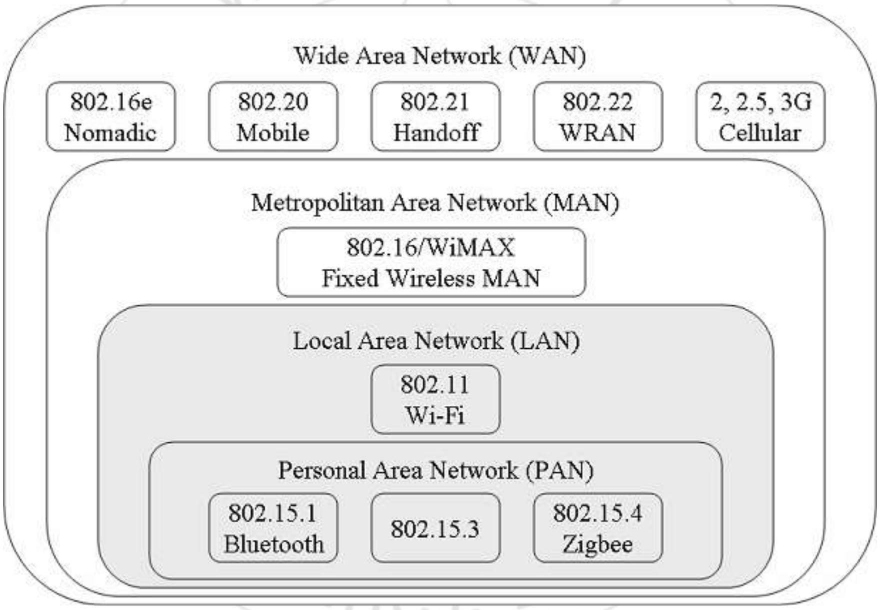

Figure 1: Wireless Standards

This paper focuses on the power management schemes used by WLANs and WPANs. The following two subsections give a brief overview of these two types of networks, along with a description of how they differ from one another in terms of their power management requirements. The final subsection is dedicated to the introduction of a subset of WPANs, known as wireless sensor networks (WSNs). Wireless sensor networks are specifically designed for very low power operation. Fig. 2 shows how these different types of networks compare in terms of data rate and power consumption. The [Ieee802.15.4] standard shown in the figure is the one most widely used by wireless sensor networks.

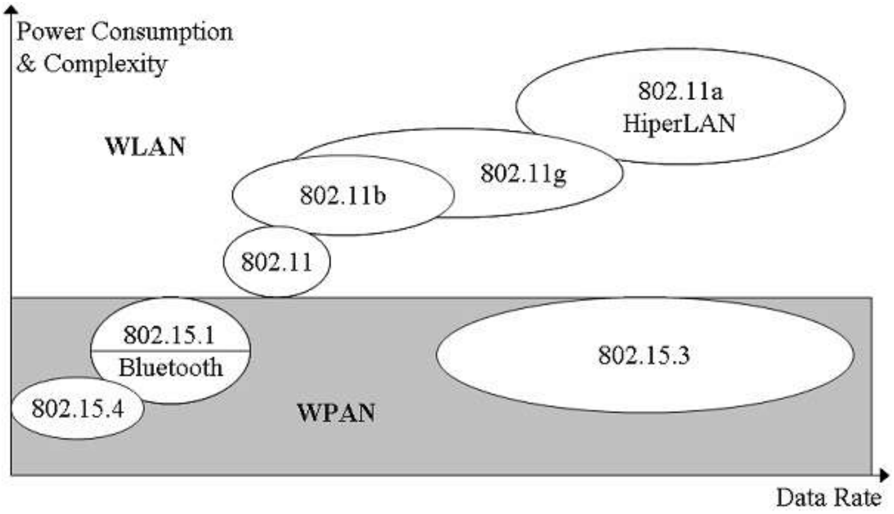

Figure 2: Power Consumption in IEEE 802 based networks

Most wireless LANs are based on the IEEE 802.11 standard [Ieee802.11] depicted in Fig. 1 and Fig. 2. This standard is also known as WiFi (Wireless Fidelity), and provides functionality for wireless devices to communicate in a way similar to the way they would on a traditional wired LAN. Devices in these networks normally operate at a higher data rate than for devices existing in a WPAN. They are usually made to communicate over longer distances as well. Because of this higher data rate and longer communication range (higher transmission power), they consume more power. To reduce the power consumed, a power management scheme known as PSM is built into the 802.11 standard. Many variations of the 802.11 standard have begun to emerge over the past few years, each with its own set of enhancements over the original 802.11 standard. Some of these improvements are for enhanced Quality of Service (802.11e), Security (802.11i), Throughput (802.11n), as well as dynamic frequency selection and transmission power control (802.11h). Of all the variations, however, only [Ieee802.11h]deals with improving the power management capabilities . Transmission power control is a method of controlling the topology of a network by reducing the power at which certain nodes in the network are allowed to transmit. However, the 802.11h enhancement standard does not explicitly define a policy for implementing a transmission power control policy; it only provides the facility for doing so.

PAN technology was developed to allow personal devices to communicate wirelessly with one another. While devices in a WLAN are able to communicate with one another over long distances and at high data rates, devices in a PAN communicate within a smaller range, and at a lower data rate. The primary standards for WPANs include 802.15.1 [Bluetooth], [Ieee802.15.3], and [Ieee802.15.4] (Zigbee). While 802.15.3 operates at data rates comparable to those in an 802.11 WLAN, the range at which devices in these networks can communicate is smaller. Because of these smaller transmission powers and lower data rates, devices in a WPAN consume less power than those in a WLAN. The 802.15.1 standard includes a power management scheme to further reduce the power consumed.

While it is desirable for devices in a WLAN or a WPAN to consume as little power as possible it is imperative for devices in a wireless sensor network . WSNs are made up of a large number of tiny low-cost, low-power, multi-functional devices used for extracting data from the environment. They are capable of taking sensor readings from the environment, processing that data, and communicating it to central location for further processing. They can essentially be thought of as extensions of the Internet into the physical world. In many situations it is desirable that the devices making up a WSN are deployed into the environment and left to run on their own accord for many months or years. Without careful power management of these devices, such deployments would not be possible. The WPAN standard designed to work with WSNs is 802.15.4 [Ieee802.15.4]. As shown is Fig. 2, 802.15.4 is not only the standard that consumes the least amount of power, but also the one having the lowest data rate. Many of the power management techniques discussed later on in this paper have been developed specifically with WSN applications in mind.

3. Energy Efficient Architecture

A base station is the interface between wireless phones and traditional wired phones. The base station, uses microwave radio communication. It is composed of several antennas mounted on a tower and a building with electronics in it at the base. When a call is made using cell phone, the cell phone and base station communicate back and forth by radio, and the radio waves they use are in the microwave region of the electromagnetic spectrum. Traffic load at the base station has significant variations in time due to a number of factors like user mobility and behaviour. Compared to the residential areas the traffic load is higher in industrial areas during daytime, and vice versa during the night. As a result, there are some cells which are always under low load, while some are under heavy traffic load. Hence, a static cell size deployment is not optimal with varying traffic conditions. Since BS consumes considerable amount of energy, selectively letting BSs go to sleep based on their traffic load can lead to significant amount of energy savings. When some cells are switched off or in sleep mode, the radio coverage can be guaranteed by the remaining active cells by filling in the gaps created. The heterogeneous multiprocessors technique discussed for sensor node platform can also be implemented at the BS. The most crucial aspect of sensor network energy optimization is the design of the sensor-node platform . It is the sensor-node hardware that consumes the energy, so if the platform is not energy-efficient, no amount of higher layer optimization will yield desired results. The workload consists of two distinct phases. The first phase, labeled “low workload,” represents the state of the network in the absence of intruders. Nodes periodically wake up, sample their sensors to detect any intruders, and, in their absence, go back to sleep. To provide high energy efficiency in this phase, a sensor-node platform should:

- Provide an ultra-low power sleep mode since the node spends a majority of its time in sleep state
- Provide a rapid wakeup capability to minimize the power management (duty-cycling) overhead.

The second phase of the sensor network’s workload represents the state when intruder activity is detected. In this state, the nodes perform a significant amount of computation and communication to locate and track the intruder. To optimize energy in this phase, the sensor node should perform its active-mode computation and communication in an energy-efficient manner. Existing sensor-node platforms are unable to simultaneously satisfy all the above requirements. While an ultra-low-power sleep mode can be achieved through techniques such as power gating, negligible power-management overhead and high active mode energy-efficiency represent conflicting objectives. This reflects the basic trade-off that processors with low power management overhead have poor active-mode energy efficiency and vice-versa. One way to overcome this conflict is to design a sensor node with both types of processors.

In the “low workload” phase, the high-end processor is power gated (i.e., completely poweredoff) and the sensor node uses a low-end processor that provides low overhead wakeup. When the sensors detect activity, the network transitions to the “high workload” phase. The high-end processor is woken up and performs the intensive computation and communication in an energy efficient manner. Once the intruder leaves, the network transitions to the “low workload” phase again and the high end processor is shut down. Such a tiered processing architecture is called a *heterogeneous multiprocessor with staged wakeup*. Unlike conventional multiprocessor systems where the processors usually operate in parallel, in this case, only one of the two processors is used to execute application functionality at any given time. The challenge then is to decide when and how to switch from one processor to the other at runtime based on the observed workload.

4. Dynamic Voltage Scaling

While shutdown techniques can yield substantial energy savings in idle system states, additional energy savings are possible by optimizing the sensor node performance in the active state. Dynamic voltage scaling (DVS) is an effective technique for reducing CPU (central processing unit) energy. Most microprocessor systems are characterized by a time-varying computational load. Simply reducing the operating frequency during periods of reduced activity results in linear decreases in power consumption but does not affect the total energy consumed per task. Reducing the operating voltage implies greater critical path delays, which in turn compromises peak performance. Significant energy benefits can be achieved by recognizing that peak performance is not always required and therefore the processor’s operating voltage and frequency can be dynamically adapted based on instantaneous processing requirement.

The goal of DVS is to adapt the power supply and operating frequency to match the workload so the visible performance loss is negligible. The crux of the problem is that future workloads are often nondeterministic. The rate at which DVS is done also has a significant bearing on performance and energy. A low update rate implies greater workload averaging, which results in lower energy. The update energy and performance cost is also amortized over a longer time frame. On the other hand, a low update rate also implies a greater performance hit since the system will not respond to a sudden increase in workload. The DVS power saving technique can be effective for both wireless sensor networks as well as cellular networks.

5. RF Transceiver Design

There are three essential parts of a base station: radio, baseband and feeder. Out of these three, radio consumes more than 80% of a base station’s energy requirement, of which power amplifier (PA) consumes almost 50%. Shockingly, 80-90% of that is wasted as heat in the PA, and which in turn requires air-conditioners, adding even more to the energy costs.

To obtain high linearity of the PAs in order to maintain the quality of radio signals, PAs have to operate well below saturation, resulting in poor power efficiency PAs based on special architectures such as digital pre-distorted Doherty-architectures and GaN (Aluminium Gallium nitride) based amplifiers seem to be more promising by pushing the power efficiency levels to over 50%.

Since GaN structures can work under higher temperature and higher voltage, they can potentially provide a higher power output. Additional improvements in efficiency can be obtained by shifting to switch-mode PAs from the traditional analog RF-amplifiers. Compared to standard analog PAs, switch-mode PAs tend to run cooler and draw less current. Operating RF transceiver is a key to save power since RF transceiver is the most power consuming part of a wireless sensor node. Obviously, reducing the RF output power will reduce the power consumption in the same transmission time, but it also makes the transmission range shorter. Because the sensor node connects to the local control centres (LCC) directly in our network topology, shorter transmission range means smaller coverage of a sub-network. In addition, smaller coverage of a sub-network also means that we will need to divide the monitoring area into more sub-networks and need to have more LCCs consequently. One thing that should be taken into account is that the coverage of each sub-network will inevitably have some overlap; therefore, we will need to schedule the operating time of sub-networks that are adjacent to each other.

If the number of sub-networks is larger, it will be more complicate to coordinate each LCC's operation. On the other hand, the number of sensor nodes is another parameter that should consider deciding the number of LCCs. We usually do not let a sub-network contain too much sensor nodes since it will make the minimum interval of a sensor node reporting the measuring result to the LCC too long, which may make the transmission delay become unacceptable.

In short, the decision of the transmission range should consider many aspects, including power consumption, required coverage, complication of scheduling problem, and the number of sensor nodes. Because there are a lot of inferring sources and obstacles that will cause interference to the wireless communication, sensor nodes that have the same distance to the LCC do not have the same received signal strength. Adjusting the RF output power according to the signal to noise ratio (S/N ratio) is a way to save power and to ensure good communication quality at the same time. Because the RF output power of this RF transceiver is also programming adjustable, we can adjust the RF output power dynamically by the program. It will not only save more power, but also can ensure good S/N ratio on every sensor node and can reduce the overlap of different subnetwork.

However, if the distance between the farthest and nearest sensor node is short, it is not necessary to adjust the RF output power dynamically since the power saved by this method is not significant in this situation. Besides RF output power, the data rate of transmission is another factor that will affect the power consumption. Intuitively, higher data rate can have lower transmission time for the same amount of data and thus can have lower power consumption.

However, the relationship between power consumption of RF transceiver and the data rate is not simply inverse proportional. The reason comes from the fact that when the data rate is higher, the sensitivity of the RF receiver will be lower. In other words, if the RF output power remains the same, the coverage of a sub-network will be smaller when the data rate is higher. Saying it in another way, we can use lower RF output power to meet the same requirement of transmission range when the data rate is lower. One thing to keep in mind is that although higher data rate seems more power-efficient, transmitting data at higher data rate will make the maximum transmission range shorter due to lower receiver sensitivity.

6. Advances in power Management

Traditionally, energy has been harvested through the use of solar panels attached to the periphery of a wireless device. These solar panels are made up of *photovoltaic* cells that convert sunlight directly into electrical current [Brown06]. The primary disadvantage of solar panels, however, is that they are large and that they require sunlight in order to work. In most wireless networking situations (but not all), it is not practical to be limited by such constraints. Laptops should not have bulky solar panels attached to them and only be operational outdoors, while nodes deployed for a wireless sensor network to take wind measurements in the Sahara desert may welcome such a technology.

Most recently, advances have been made with a technology involving the use of *piezoelectric* materials. Piezoelectricity is the ability to create an electric current by suppressing certain types of crystal to mechanical stress. The primary advantages that piezoelectric materials have over solar panels is that they are small, do not require access to direct sunlight, and they operate with about a 70% mechanical to electrical transduction efficiency. Solar panels achieve only about 16-18% efficiency [Brown06].

While the science behind both solar energy harvesting and piezoelectric materials has been well understood for quite some time, their potential in the wireless networking domain are just now being realized. Section 5 discusses some of these applications and what products are being manufactured to support them.

7. Industry Developments

Technique "ambient backscatter", which can let devices use the cellular and TV transmissions already being broadcast around us, reflecting those signals to send and receive their own data to similar devices, without the need for a battery or other power source. It is going to have applications in a number of areas including wearable computing, smart homes and self-sustaining sensor networks. A small testing network made the devices to communicate with each other, as sensors would in a real-world application, even up to 6.5 miles away from a TV tower. The future of the Internet of Things might get a jumpstart with the ability to use wireless power transmission for its sensors and microcomputers, because removing the need for a power source will greatly increase the possibilities for connected devices. This technology could be built into devices that also have an onboard battery, such as cellphones, so that even if that battery were to die, text messages could still be sent using ambient backscatter, powered by a TV tower.

The Echo Water and Echo Electricity devices are designed to analyze the user's consumption of two major inputs to living spaces, and then recommend options for reducing the use of both water and electricity (and saving money as a consequence). Echo Electricity sensing system detects current and voltage signatures within a building's electrical circuit using a single sensor that can be placed at the meter, breaker box, or in an outlet. These signatures are analyzed using advanced machine learning-based algorithms that can determine exactly which devices are being used, when they are being used and how much electricity they consume. This information can show a homeowner or building manager where electricity is being wasted, which devices need replacement or repair, and can also provide valuable insight into patterns of use and occupancy, enabling other valuable applications such as home security or assisted living. The Echo Water solution works in a similar way, except that it monitors water instead of electricity. Both are built on wireless home automation network platform, which extends the devices and relays the data to allow for real-time monitoring and management of connected devices.

Robotic eel can efficiently scan a source of water for pollution and wirelessly deliver the data it gathers in real time. It is used to find and follow signs of pollution. Water quality samples are typically taken by hand on a regular schedule, but the process is slow and only represents the quality of the water at the spots where it was sampled. Team of robotic eels could take measurements and cover the expanse of a body of water. “There are many advantages to using swimming robots. They can take measurements and send us data in real-time – much faster than if we had measurement stations set up around the lake. And compared with conventional propeller-driven underwater robots, they are less likely to get stuck in algae or branches as they move around. The robotic eel is outfitted with sensors that make it able to test the water for changes in conductivity and temperature as well as signs of toxins. The robot is made of several modules, each containing a small electric motor and different sensors. The modular design allows researchers to add or take from its length and change the robot's make up as needed for each task. The robot features traditional sensors measuring temperature and conductivity, but there are also biological ones comprised of bacteria, crustaceans and fish cells that detect the presence of toxins. The researchers observe any changes to the organisms when placed in the water. For instance, the bacteria will luminescence when exposed to even very low concentrations of mercury. Luminometers measure the light given off by the bacteria and that information is transmitted to a central hub for analysis. The tiny Daphnia crustaceans are observed in clean water compared to the water sample and any changes in movement are used to detect pollutants. The fish cells are grown directly on electrodes and then exposed to the water. If toxins are present, the cells move apart and the flow of electricity is interrupted.

WaterBee, may be a sign of things to come in "smart" irrigation, incorporating networked sensors that can be centrally monitored and administered, letting water managers and farmers optimize their water use, right from their smartphone. WaterBee consists of a series of sensors that measure soil water content ,environmental parameters that influence evapo transpiration, and indicators of crop development or physiological status. The data gathered from these sensors is sent across a low cost, low power consumption ZigBee wireless sensor network. These sensors are effectively distributed over the cultivated area, given that different areas of the field (or fields) have different water requirements.

The sensors monitor these parameters and send readings across a Zigbee mesh network to a GPRS gateway which sends all of this data to a central web service which uses an intelligent software application to automatically analyse the data and act upon it by selectively activating irrigation nodes only in the areas required. This data is fed into an intelligent software package that uses intelligent agents in order to act upon the information they are receiving from the sensors. The outputs and irrigation recommendations are presented to the user on a Smartphone App or Web Browser. Using the system gives growers more control over their irrigation by delivering accurate data on field and crop conditions, thereby lowering their costs and raising their yields. The access to real-time data on the state of the plants and the levels of moisture in the soil, right from a smartphone or browser, allows users to control and monitor their system for optimal irrigation scheduling. "WaterBee intelligent irrigation modeling and scheduling system goes well beyond the state-of-art, with its unique Soil-Moisture Model for optimal water use, continuously self-adapting to each user’s situation and business objectives, using machine learning approaches, and its open web-enabled architecture facilitates future integration with all environmental data in line with the European INSPIRE Directive.

8. Summary

In this survey, a variety of different energy conserving techniques for wireless networks have been explored. Although the scope of this paper has been limited exclusively to WLANs and WPANs, many of the techniques presented are universal and can be used to perform power management in any type of network. A brief overview of each type of network has been given, including a description of a subset of WPANs known as Wireless Sensor Networks. It was shown that while WLANs and traditional WPANs may achieve longer lifetimes through the use of the power management techniques presented, low power design in WSNs is an essential feature and thus required particular focus in this paper.

It has been shown that the current research being conducted for power management in wireless networks using latest techniques. While each of these techniques provides power savings on their own, they can all be combined to achieve better performance than any one of them individually.

Products are just now being manufactured that exploit the use of these types of techniques. No one seems to want to save power if it means sacrificing performance. The quest for the everlasting battery source has not yet produced any results. As long as there is the need to continue driving down the amount of energy consumed by a wireless device, more and more research will continue to be done in this field, more and more standards will continue to emerge, and more and more products will continue to be manufactured.

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