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Dynamic Power Management in Wireless Sensor Network

John, T. Ogbiti [1], Magaji, S. Abubakar[2], Henry C. Ukwuoma[3] and A. A. Obiniyi[4]

1. Mathematics Department, Faculty of Science Ahmadu Bello University Zaria, Kaduna State, Nigeria.
2. Department of Mathematical Science, Faculty of Science Kaduna State University, Kaduna Nigeria.
3. The National Institute for Policy and Strategic Studies, Kuru, Jos Plateau State, Nigeria.
4. Mathematics Department, Faculty of Science Ahmadu Bello University Zaria, Kaduna State, Nigeria.

ABSTRACT
This research focuses on reducing or minimizing the power consumption, thereby increasing the network lifetime and also demonstrates a methodology for power consumption evaluation of WSN. The research also analyzes the energy consumption of ad hoc nodes using IEEE 802.11 interfaces; this was achieved using OPNET simulator. The evaluation takes into account the properties of the medium access protocol and the process of forwarding packets in ad hoc mode. The key point is to determine the node lifetime based on its average power consumption. The average power consumption is estimated considering how long the node remains sleeping, idle, receiving or transmitting.

I Background to Study

Wireless Sensor Networks (WSN) deployment is fast gaining wide spread attention in different field of studies such as military, house-holds, factories, environment monitoring and control field (e.g., robot control), high-security smart homes, tracking and identification and personalisation. Wireless sensor nodes are autonomous and many wireless sensor networks applications are being designed to either provide an automatic response to certain situations or serve as a notification system to some higher order authority of action. It is also known that wireless sensor networks have the ability to generate huge data which sometimes can prove really difficult to manage and analyse (Ye et al., 2005).

Although more than 90% of sensors are still wired, wired sensor networks have been replaced by wireless sensor networks due to the cost and delay of deployment. The dominant factor of constructing wired sensor networks is the wiring cost. In addition, wired networks require considerable time to implement. In case of wireless sensor network, the deployment is rather simple, in many cases, just dropping off sensor nodes from an airplane into the target area instead of wiring from the target area to monitoring station. Wireless sensor networks can be used in variety of applications that allow existing information systems to obtain and process data from physical world. In environment monitoring, one of the earliest applications of wireless sensor network, wireless sensors are used to monitor animals and plants in wildlife habitat. Other related applications include monitoring of water pollution, wildfires, and earthquakes. In the military battlefield, where there is no infrastructure and it is very hard to access and deploy the sensor networks, the wireless sensor networks can be rapidly deployed to detect the enemy target and to track their movements in real-time. Commercial applications include the monitoring and tracking of assets, monitoring of the conditions of industrial equipment, automated meter reading, and warehouse management using RFID technologies (Dharma and Quin-an, 2011).

Wireless sensor networks can also be used in structural health monitoring of large structures such as airplanes, buildings, and bridges. With the dedicated short range communication (DSRC) standard, car-to-car networking with sensors can be available to provide emergency warning, traffic monitoring, and driver safety assistance. One of the most important areas of wireless sensor network applications is health monitoring of patients in a hospital. Energy is a limited resource in wireless sensor networks. In fact, the reduction of power consumption is crucial to increase the lifetime of low power sensor networks. Several approaches on dynamic power management have contributed to reduce the power consumption, but few of them consider the application constraints to optimize it. Wireless sensor networks represent a recent research area, due to their great capability of performing environment monitoring and information collection. However, a sensor node has limited resources such as processing and storage capacity. Furthermore, a sensor node is typically battery operated, which means that it is also energy constrained (Asada, 1998).

A sensor node can only operate as long as its battery maintains power. Therefore aspects like architecture, communication protocols, algorithms, circuits and sensing must be energy efficient. Additionally, a Dynamic Power Management (DPM) can reduce the power consumption and, consequently, improve the network lifetime.

Different DPMs techniques have been proposed to reduce the power consumption in sensor nodes and in general battery-powered embedded systems. Most of these techniques exploit the sleep and idle states, where the power consumption is lower, following the philosophy of getting the work done as quickly as possible and sleep. Furthermore, the communication task is the major consumer of energy, and should be performed only when it is really needed.

1.1 Research Motivation

A typical sensor node is compact, tiny, and inexpensive, but it integrates the functionalities of sensing, data processing and computation, and communication. It is normally operated by an attached power supply that is usually a non rechargeable or non replaceable battery. Dynamic Power Management schemes have been proposed to reduce the power consumption by selectively shutting down idle components. Much work has been done exploiting sentry-based power management, Dynamic Voltage Scaling (DVS) and Dynamic Voltage and Frequency Scaling, software and operating system power management and battery state awareness power management (Benini, 2002). However, in this work a dynamic power management technique is proposed that considers the application requirements and the sensor node operation as a unique model, to achieve low power consumption balanced against the required application responsiveness. To achieve low power consumption by exploiting sleep, idle, receive and transmit states when the environment changes as expected.

II Overview of Wireless Sensor Network

Emergence of the concept of multi-hop ad-hoc wireless networks, low-power electronics, low-power, short-range wireless communication radios, and intelligent sensors is considered the major technological enabler for deployment of sensor networks (SNs). The goal of this survey is to identify key architectural and design issues related to sensor networks, critically evaluate the proposed solutions, and outline the most challenging research directions. The evaluation has three levels of abstraction:

i. Individual components on SN nodes (processor, communication, storage, sensors and/or actuators, and power supply)
ii. Node level
iii. Distributed networked system level

Special emphasis is on architecture, system software, to some extent, and new challenges related to using new types of components in networked systems. The evaluation is guided by anticipated technology trends and current and future applications. The main conclusion of the analysis is that the architectural and synthesis emphasis will be shifted from computation and, to some extent communication, components to sensors, actuators, and different types of sensors and applications that require distinctly different architectures at all three levels of abstraction (Sadler, 2005)

2.1 What is a Sensor?

A general definition of a sensor is “a device that produces measurable response to a change in a physical or chemical condition.” More specifically, a sensor is "a device that responds to a stimulus, such as heat, light, or pressure, and generates a signal that can be measured or interpreted." The Sensor Network community often (but not always) defines a sensor node as a small, wireless device, capable of responding to one or several stimuli, processing the data and transmitting the information over a short distance using a radio link. Sensor nodes employ electronic circuits that minimize power consumption. Typically sensors are thought of as measuring light, sound and temperature. However, sensors can measure other variables, such as electromagnetic fields or vibrations. Sensors transmit values wirelessly to one or several sinks (Singh et al., 2010)

A Sensor Network is a wireless, ad-hoc network, made of a large number (hundreds or thousands) of nodes, whose positions occur randomly. The OSI model and the classic layered view of communication networks may or may not apply directly to sensor networks. Other models of sensor network communications include a protocol stack model that includes physical, medium access control, network, transport and application layers as well as power management, mobility management and task management planes. However, no model is used universally (Singh et al., 2010).

2.2 What are Wireless Sensor Networks?

Wireless sensor networks consist of distributed, wirelessly enabled embedded devices capable of employing a variety of electronic sensors. Each node in a wireless sensor network is equipped with one or more sensors in addition to a microcontroller, wireless transceiver, and energy source. The microcontroller functions with the electronic sensors as well as the transceiver to form an efficient system for relaying small amounts of important data with minimal power consumption (Culler and Clark, 2004).

The most attractive feature of wireless sensor network is their autonomy. When deployed in the field, the microprocessor automatically initializes communication with every other node in range, creating an ad-hoc mesh network for relaying information to and from the gateway node. This negates the need for costly and ungainly wiring between nodes, instead relying on the flexibility of mesh networking algorithms to transport information from node to node. This allows nodes to be deployed in almost any location. Coupled with the almost limitless supply of available sensor modules, the flexibility offered by wireless sensor networks offers much potential for application-specific solutions. The diagram in Figure 2.1 and 2.2 shows a wireless sensor and MicroStrain's line of smart, wireless sensor nodes (Culler and Clark, 2004).

2.3 OPNET Simulator

OPNET (Optimized Network Engineering Tool) provides a comprehensive development environment for the specification, simulation and performance analysis of communication networks. A large range of communication systems from a single LAN to global satellite networks can be supported. Discrete event simulations are used as the means of analyzing system performance and their behaviour. The key features of OPNET are summarized, thus:

i. **Modelling and Simulation Cycle:** OPNET provides powerful tools to assist user to go through three out of the five phases in a design circle (i.e. the building of models, the execution of a simulation and the analysis of the output data).
ii. **Hierarchical Modelling:** OPNET employs a hierarchical structure to modelling. Each level of the hierarchy describes different aspects of the complete model being simulated.
iii. **Specialized in communication networks:** Detailed library models provide support for existing protocols and allow researchers and developers to either modify these existing models or develop new models of their own
iv. **Automatic simulation generation:** OPNET models can be compiled into executable code. An executable discrete-event simulation can be debugged or simply executed, resulting in output data.

This sophisticated package is supplied with a range of tools which allows developers specify models in great detail, identify the elements of the model of interest, execute the simulate on and analyze the generated output data (Li et al., 2001).

2.4 Related Work

Sensor Protocols for Information via Negotiation (SPIN) makes good the deficiencies of classic flooding by negotiation and resource adaptation. Using SPIN routing algorithm, sensor nodes can conserve energy by sending the metadata that describes the sensor data instead of sending all the data. SPIN can reduce the power consumption of individual node, but it may decrease the lifetime of the whole network due to extra messages (Alonso et al., 2004).

Bhardwaj and Chandrakasan (2008) computed the upper bound of active lifetime in terms of the routing algorithms. But they did not consider that the first tier nodes determine the lifetime of the whole network. They measured the lifetime of the network as the time of first loss of the coverage. That is, they did not care the connectivity. They elaborated their work by taking into account the data aggregation and random topology.

James et al. (2008) evaluated the power consumption of sensors, using an oscilloscope to determine power consumption in each of several states. However tests were conducted over short time intervals and with no statistical validation.

Anastasi et al. (2006) determined energy uptake of a sensor node by measuring the average current consumption with a voltmeter. This method has been used extensively as a guide for simulations and the design of low power consumption communication protocols.

Mhatre (2006) obtained the minimum number of sensor nodes, cluster heads, and battery energy to ensure at least T unit of lifetime. They assume two types of sensor nodes: node 0 is sensor node and node 1 is cluster head. The main result is that the number of cluster heads should be the order of square root of the number of sensor nodes. They don't give exact formula for the maximum lifetime of the network. It is difficult for the assumption that cluster heads directly communicate with the base station to be applied to general applications. It was observed that the nodes close to the cluster heads have high energy burden due to relaying of packets. But one of their important observations, the sharp cut off effect to maximize the lifetime does not hold at all time.
Pan (2010) observed that the first tier nodes are important for the lifetime of the whole network. They provided approaches to maximize the topological lifetime of the network in terms of the base station placement for the two-tiered sensor networks where sensor nodes are deployed in clusters.

This research presents a power management technique that considers the data transmission, reception, idle listening time, sensing, and data processing as the power consumption of a node. The node lifetime T which present the time before the energy of the node reaches zero in a network are measured. Lastly a simulation was done on WSNs that distribute energy equally in a network, which make is work different from other works that has been done on power management in wireless sensor network.

III Simulation Tool

There are many simulators that have been created. However, a lot of them were written for specific purposes testing just one network component or protocol. OPNET IT Guru is an application that allows you to model a wide variety of networks and situations. The application can be used to test the performance of a modelled network configured with predefined parameters. After model construction, a simulation can be run to gather user-defined statistics. Results are presented as graphs for easy evaluation. The OPNET Modeller software package is among the most popular and most comprehensive tools available in the market for modelling new communication technologies and protocols. OPNET Modeller includes a vast model library of communications devices, communication mediums, and cutting-edge protocols. OPNET simulator is selected for this research work (Kottapalli, 2003)

3.1 Energy Consumption in WSNS

As a microelectronic device, the main task of a sensor node is to detect phenomena, carry out data processing timely and locally and transmit or receive data. A typical sensor node is generally composed of four components; a power supply unit, a sensing unit, a computing unit and a communicating unit. The sensing node is powered by a limited battery, which is impossible to replace or recharge in most application scenarios. Except for the power unit, all other components will consume energy when fulfilling their task. Extensive study and analysis of energy consumption in WSNs are available (Najm, 1994).

3.1.1 Sensing Energy

The sensing unit in a sensor node includes the embedded sensor and/or actuator and the analogue–digital converter. It is responsible for capturing the physical characteristics of the sensed environment and converts its measurements to digital signals, which can be processed by a computing/processing unit. Energy consumed for sensing includes:
(1) Physically signal sampling and conversion to electrical signal;
(2) Signal conditioning; and
(3) Analogue to digital conversion.
It varies with the nature of hardware as well as applications. For example, interval sensing consumes less energy than continuous monitoring; therefore, in addition to designing low-power hardware, interval sensing can be used as a power-saving approach to reduce unnecessary sensing by turning the nodes off in the inactive duty cycles. However, there is an added overhead whenever transiting from an inactive state to the active state. This leads to undesirable latency as well as extra energy consumption. However, sensing energy represents only a small percentage of the total power consumption in a WSN. The majority of the consumed power is in computing and communication (Najm, 1994).

3.1.2 Computing Energy

The computing/processing unit is a microcontroller unit (MCU) or microprocessor with memory. It carries out data processing and provides intelligence to the sensor node. A real-time micro-operating system running in the computing unit controls and operates the sensing, computing, and communication units through micro device drivers and decides which parts to turn off and on. Total computing energy consists of two parts: switching energy and leakage energy. The switching energy is determined by supply voltage and the total capacitance switched by executing software. The pattern of draining the energy from the battery affects the total computing energy expense. For example, a scheme of energy saving on computation is dynamic voltage scaling (DVS), which can adaptively adjust operating voltage and frequency to meet the dynamically changing workload without degrading performance. The leakage energy refers to the energy consumption while no computation is carried out. Therefore, it is critical to minimize leakage energy.

The concept of system partitioning can also be used to reduce computing energy in sensor nodes. Two practical approaches include removing the intensive computation to a remote processing centre that is not energy constrained, or spreading some of the complex computation among more sensors instead of overloading several centralized processing elements energy expenditure for computing is much less compared to that for data communication. Therefore, trading complex computation/data processing for reducing communication amount is effective in minimizing energy consumption in a multi hop sensor network (Najm, 1994).

3.2 Power Management

A wireless sensor node is typically battery operated and is thus energy constrained. To maximize the lifetime of the sensor node after its deployment, all aspects, including circuits, architecture, algorithms and protocols, must be made energy efficient. Once the system has been designed, additional energy savings can be obtained by using dynamic power management concepts whereby the sensor node is shut down if no interesting events occur or slowed down during periods of reduced activity. Such event driven power consumption is critical for obtaining maximum battery life from the sensor node (Anna and Anastasi, 2006).

Although shutdown techniques can yield substantial energy savings in the idle states of the system, additional energy savings are possible by optimizing the performance of the sensor node in its active state. Dynamic voltage scaling (DVS) is a very effective active power management technique for reducing processor energy consumption. Most microprocessor-based systems are characterized by a time varying computational load. Simply reducing the operating frequency during periods of reduced activity results in linear decrease in power consumption but does not affect the total energy consumed per task. Reducing the operating voltage implies greater circuit delays that in turn mean that peak performance is compromised. Significant energy benefits can be achieved by recognizing that peak performance is not always required and therefore the operating voltage and frequency of the processor can be dynamically adapted based on instantaneous processing requirements. The goal of DVS is to adapt the power supply and operating frequency to match the workload so that the visible performance loss is negligible (Anna and Anastasi, 2006).

Dynamic power management (DPM) technique improve the energy efficiency of sensor nodes. DPM is an effective tool to reduce system power consumption without significantly degrading performance. The embedded OS is used to facilitate active and idle power management (Anna and Anastasi, 2006).

3.2.1 Idle Power Management

Efficient DPM in idle mode requires power-differentiated states and optimal OS policies to transition to and from various states. The basic idea behind idle power management is to shut down devices when they are not needed and wake them when necessary. Formulating an optimum shutdown policy, in general is a nontrivial problem. If the energy and performance overheads in transitioning to sleep states were negligible, a simple greedy algorithm that makes the system go into the deepest sleep state as soon as it is idle would be perfect (Anna and Anastasi, 2006).

However, in reality, transitioning to a sleep state has the overhead of storing the processor state and shutting off the power supply. Waking also takes a finite amount of time. Therefore, implementing the right policy for transitioning to various sleep states is critical for effective idle power management.

Most power-conscious devices support multiple power-down modes offering different levels of power consumption and functionality. An embedded system with multiple such devices can have a set of power states based on various combinations of device power state. In fact, an open interface specifications called the advanced configuration and power management interface (ACPI) jointly promoted by Intel, Microsoft, and Toshiba; standardizes how the OS can interface with devices characterized by multiple power states to provide dynamic power management. ACPI controls the power consumption of the whole system as well as the power state of each device. An ACPI-compliant system has five global states — SystemStateS0 (working state) and SystemStateS1 to SystemStateS4 — corresponding to four different levels of sleep states. Similarly, an ACPI-compliant device has four states: PowerDeviceD0 (the working state) and PowerDeviceD1 to PowerDeviceD3. The sleep states are differentiated by the power consumed, the overhead required in going to sleep, and the wake-up time (Anna and Anastasi, 2006).

3.2.2 Active Power Management

The OS can be used to manage active power consumption in an energy-constrained sensor node. It reduces the operating frequency and voltage to a level just enough for the sensing application so that no visible loss is observed in performance while the energy consumption is reduced.

Dynamic voltage scheduling is a very effective technique for reducing CPU energy. Several sensor systems are characterized by a time-varying computational load. Simply reducing the operating frequency during periods of reduced activity results in a linear decrease in power consumption but does not affect the total energy consumed per task, as shown in Figure 3.2(a) (the shaded area represents energy). Reduced operating frequency implies that the operating voltage can also be reduced. Because the switching power consumption scales linearly with frequency and quadratically with supply voltage, quadratic energy reduction can be obtained as shown in Figure 3.2(b). Significant system energy savings can be realized by recognizing that peak performance is not always required and therefore the operating voltage and frequency of the processor can be dynamically adapted based on instantaneous processing requirement (Asada, 1998)

3.3 Sources of Power Consumptions

In this section we present all power consumption sources used in our models.

i. **Collisions** When two or more packets arrive at the receiver at overlapping times, those packets collide with each other. In this case, the senders have to retransmit the packets. This increases the number of packet transmissions and the energy consumption. MAC protocols provide different methods to reduce the collisions such as collision avoidance backoffs and RTS/CTS schemes (Benin and Micheli, 2002).
ii. **Transmissions/Receptions** Radio transmissions and receptions are necessary and unavoidable for the actual data transfer.
iii. **Overhearing** This source of power consumption is rooted in the broadcast characteristics of wireless communication. That is even if a packet is destined to a specific receiver all nodes within the transmission range of the sender can hear the packet. Thus, the neighbouring nodes that are not the intended receiver still receive and process the packet before discarding it. The amount of overhearing increases with the density of the nodes (Benin and Micheli, 2002).
iv. **Idle listening** Idle listening occurs when nodes wait to receive packets by listening idly to the channel. Measurements show that for most transceivers the energy needed to listen to the wireless channel is almost as high as that for packet receptions. In many applications sensor nodes are in idle listening state for long period of time. Thus, idle listening is the dominant component of power consumption of MAC protocols in WSNs (Benin and Micheli, 2002).
v. **Sensing** The power consumption for sensing the environment differs from application to application. In some applications it may be a large percentage of the total power consumption. However, this component is not related to the MAC protocol, and therefore is not consider in the analysis of MAC protocols (Benin and Micheli, 2002).
vi. **Sleep** When nodes go to sleep, the radio is turned off. Furthermore, we assume that the CPU is also at stand-by mode to minimize the power consumption when it is in sleep state.

3.4 Dynamic Power Optimization at the Node Level

Energy consumption at sensor node level describes the lifetime of the network. From a functionality perspective, energy is consumed for sensing, computation, and communications. Power conservation can be achieved in any of these functions. First, it should be noted that workload in WSNs typically has the characteristic of burstiness. Therefore, some nodes or certain components of nodes should switch to power-saving states between consecutive bursts while the functionality and Quality of Service are still maintained. Dynamic power management (DPM) is an example of this approach. As listed in Table: 3.1 a particular combination of component states will determine a specific node state (Buettner et al., 2006)

Table 3.1: States of the Sensor Node and its Components

No.	Node State	MCU	Memory	Sensor and A/D	Radio
S0	Transmitting	Active	Active	On	Tx
S1	Receiving	Active	Active	On	Rx
S2	Ready	Idle	Sleep	On	Rx
S3	Observing	Sleep	Sleep	On	Rx
S4	Standby	Sleep	Sleep	On	Off
S5	Sleep	Sleep	Sleep	Off	Off
S6	Off	Off	Off	Off	Off

State s_0: is the completely active state of the node where it can sense, process, transmit, and receive data.
State s_1: the node is in sense and receive mode.
State s_2: is similar to **state s_1** except that is Idle and waked up when the sensor or the radio receives data.
State s_3: is the observing mode in which the node sleeps.
State s_4: the node is in sense and receive mode while the processor is in standby.
State s_5: is similar to **state s_4** except that the radio receiver is powered down.
State s_6 represents the completely off state of the device.

For a sensor node, the states in decreasing order of power consumption are: transmitting, receiving, ready, observing, standby, sleep, and off. The state transition diagram of a sensor node is shown in Figure 3.3. However, transitions among states have power consumption and latency costs. Specifically, some transitions, for example, from "off" to "sleep," might cost much more energy than others, such as from "sleep" to "active." As a result, well-designed control algorithms are needed to achieve the trade-off between power saving and latency, power consumption, and state transitions (Buettner et al;., 2006).

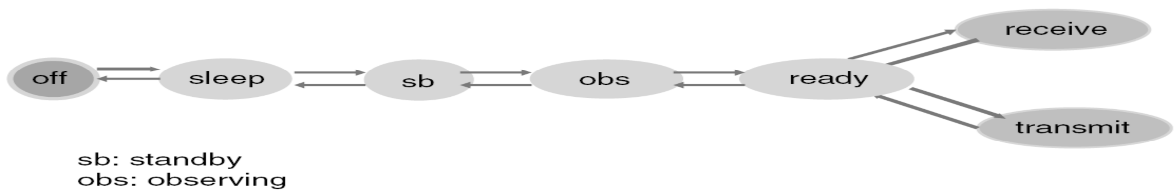

Figure 3.1: The state transition diagram of a sensor node (Buettner et al., 2006).

3.5 Energy Consumption of the Nodes

The analyses presented in this research assumes the use of IEEE 802.11b interfaces operating in ad hoc mode at 11Mbps using the Distributed Coordination Function (DCF), with RTS/CTS handshake. We can model the average power (P_m) consumed by the interface as

$$P_m = t_{sl} * P_{sl} + t_{Id} * P_{Id} + t_{Rx} * P_{Rx} + t_{Tx} * P_{Tx} \quad . \quad . \quad (3.1)$$

Where t_{sl}, t_{Id}, t_{Rx} and t_{Tx} are the fractions of time spent by the interface in each of the possible states: Sleep, Idle, Receive, and Transmit respectively, these fractions of time satisfy the condition. Analogously, P_{sl}, P_{Id}, P_{Rx} and P_{Tx} are the powers consumed in the four states considering P_m and the initial energy of the node (E), we can calculate the node lifetime (T_v), which represents the time before the energy of the node reaches zero, as

$$T_v = \frac{E}{P_m} \quad . \quad . \quad . \quad (3.2)$$

The analysis measurement from Table 4.2: node energy consumptions in AP _0 at station STA_0. It also shows the consumption of the four states relative to the Idle, Sleep, Received and Transmit. We can compute the Power Management (Pm) and the node Lifetime (T_v), which represents the time before the energy of the node reaches zero

Table 3.2: Node Energy Consumption

Operation	Current(ma/s)
Sleep	0.280
Idle listening	0.660
Receive	1.376
Transmit	2.332

IV SIMULATION, RESULT AND DISCUSSION

4.1 Power Consumption

We classify energy efficient MAC protocols for WSNs into two groups; synchronization-based and preamble-based.

i. In synchronization-based MAC protocols, the sampling period is divided into fixed size frames. Sensor nodes wake up and go to sleep once during each frame. To send and receive frames, all nodes in a neighbourhood wake up and go to sleep at the same time. Therefore, synchronization- based MAC protocols provide (and use) synchronization mechanisms. Synchronization-based MAC protocols include 802.11 power saving mode (Kari and Mishra, 2002).

ii. In preamble-based MAC protocols, the nodes are not synchronized with each other. Instead, senders use a long preamble to wake up receivers. In these protocols the receiver sleeps for a long time and wakes up for a very short time to check for the existence of a preamble. If the receiver does not detect any preamble, it goes back to sleep immediately. If it detects the preamble, the node goes back to sleep after performing the protocol specific radio operations. We define a frame in the preamble-based protocols as the time combining the sleep time and the time to check the preamble. Unlike in synchronized-based protocols, the number of frames during each sampling period in preamble-based protocols varies depending on the traffic load during the sampling period (kari and Mishra, 2002).

4.2 Power Consumption Analysis of 802.11 Basic Mode (ad-hoc)

For comparison purposes, we examine the power consumption of the 802.11 protocol in ad- hoc mode. The initial design of this protocol assumes that all nodes are within transmission range of each other. All nodes attempt to send BEACON packets to synchronize with each other. Only one BEACON packet is sent among all nodes in a neighbourhood during a beacon interval. If a node has a packet to transmit and the medium is free for the duration of a (DIFS), the node starts sending the packet as we assume no collisions and no collision avoidance. As shown in Figure 4.1, nodes are always in receiving mode unless they are transmitting (Macii et al., 1998).

4.3 Simulation Process Configuration

This is an 89-node WLAN network highlighting different WLAN algorithms and features specified in IEEE 802.11 and 802.11b standards. Like various rates, RTS/CTS .frame exchange, data packet fragmentation and roaming.

The network consists of a central bridge, 8 APs (access points) connected to that bridge, who's BSS IDS are set as 0 to 7 (AP_0 = BSS 0 ...), and 10 WLAN stations in the BSS of each AP. The stations that are in BSS 0 initially rotate in clockwise direction and complete their circle towards the end of the simulation. Hence, they are expected to get connected to all existing APs while they are traversing their trajectory. Similarly, the stations that reside in BSS 6 initially, visit each AP in counter-clockwise direction throughout the simulation. All the other stations are stable during the simulation. Different APs use different WLAN data transmission rates: AP_0 and AP_4 1Mbps, AP_1 and AP_5 2Mbps, AP_2 and AP_6 5.5Mbps, and AP_3 and AP_7 11 Mbps. Additionally RTS/CTS frame exchange is enabled for AP_2, AP_3, AP_4 and AP_6, and fragmentation of large packets is enabled for AP_1, AP_3, AP_5 and AP_6.

These parameters of station nodes are configured same way as they are configured for their initial APs. Each station generates on average one packet for every 1.2 seconds that is randomly destined for another station in the network. The transmission powers of the WLAN nodes are set to a value (2mW) that is lower than the default value in order to reduce the coverage area of the APs so that these areas don't overlap with each other significantly and a mobile STA is handed over to the next AP when it is around the mid-way between two APs. There is also a Wireless LAN MAC Address parameter, which is an internal station address that is usually set as auto assigned unless specific configuration is required. You can configure the WLAN parameters on a per-interface basis for nodes with multiple wireless interfaces. Each wireless node has the same set of wireless LAN attributes. These attributes are grouped under the Wireless LAN Parameters compound attribute.

Table 4.1: WLAN Parameters

(Wireless LAN Parameters) Table

Attribute	Value
BSS Identifier	Auto Assigned
Access Point Functionality	Disabled
Physical Characteristics	Direct Sequence
Data Rate (bps)	11 Mbps
Channel Settings	Auto Assigned
Transmit Power (W)	0.005
Packet Reception-Power Threshold (dBm)	-95
Rts Threshold (bytes)	None
Fragmentation Threshold (bytes)	None
CTS-to-self Option	Enabled
Short Retry Limit	7
Long Retry Limit	4
AP Beacon Interval (secs)	0.02
Max Receive Lifetime (secs)	0.5
Buffer Size (bits)	256000
Roaming Capability	Disabled
Large Packet Processing	Drop
PCF Parameters	Disabled
HCF Parameters	Not Supported

Details | Promote | OK | Cancel

The maximum communication distance between two WLAN nodes is a function of three parameters: the transmission power of the sending node, the path-loss propagation model, and the reception power threshold (receiver sensitivity) of the receiving node. Based on the configured values of these parameters, we model WLAN networks in which the communication distance is more than 300 meters. The IEEE 802.11 standard limits the distance between WLAN nodes to 300 meters. Therefore, WLAN networks that extend beyond 300 meters might incur performance degradation in the WLAN MAC algorithm. We configure the transmitter power on each WLAN device. Transmission range is configured in the Transmit Power attribute. The following attributes are used for configuring WLAN network models as shown in Figure 4.2 and Figure 4.3.

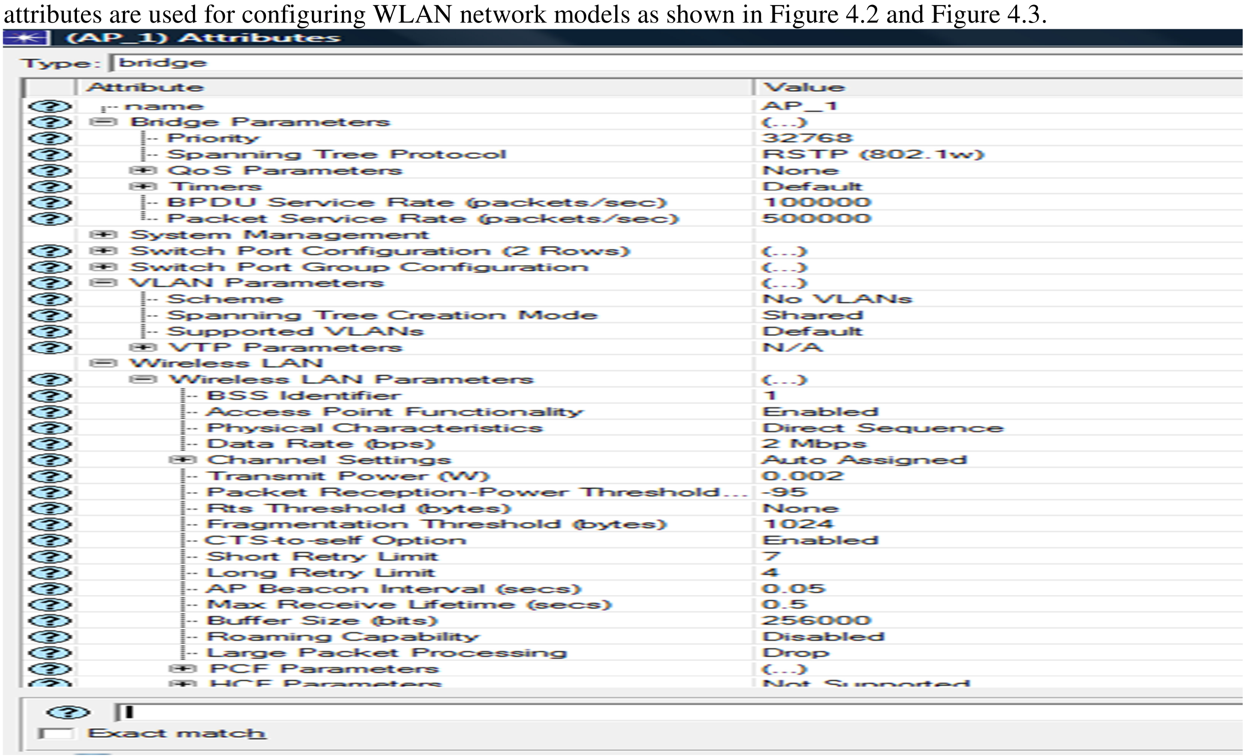

Figure 4.2: Access Point Attribute and value

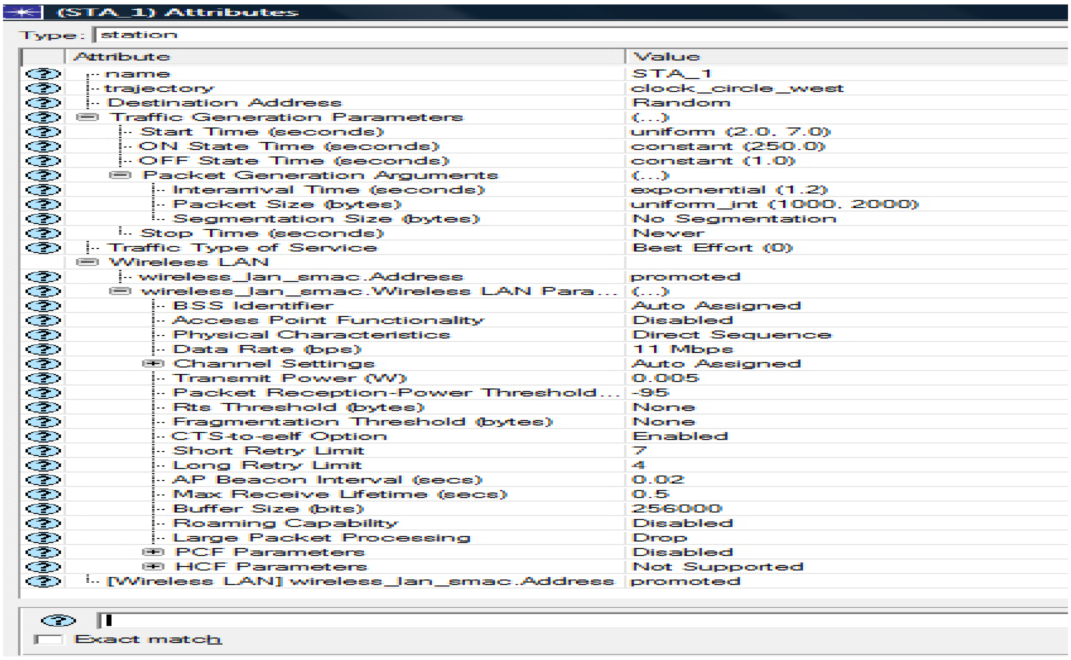

Figure 4.3: Station Parameter Value

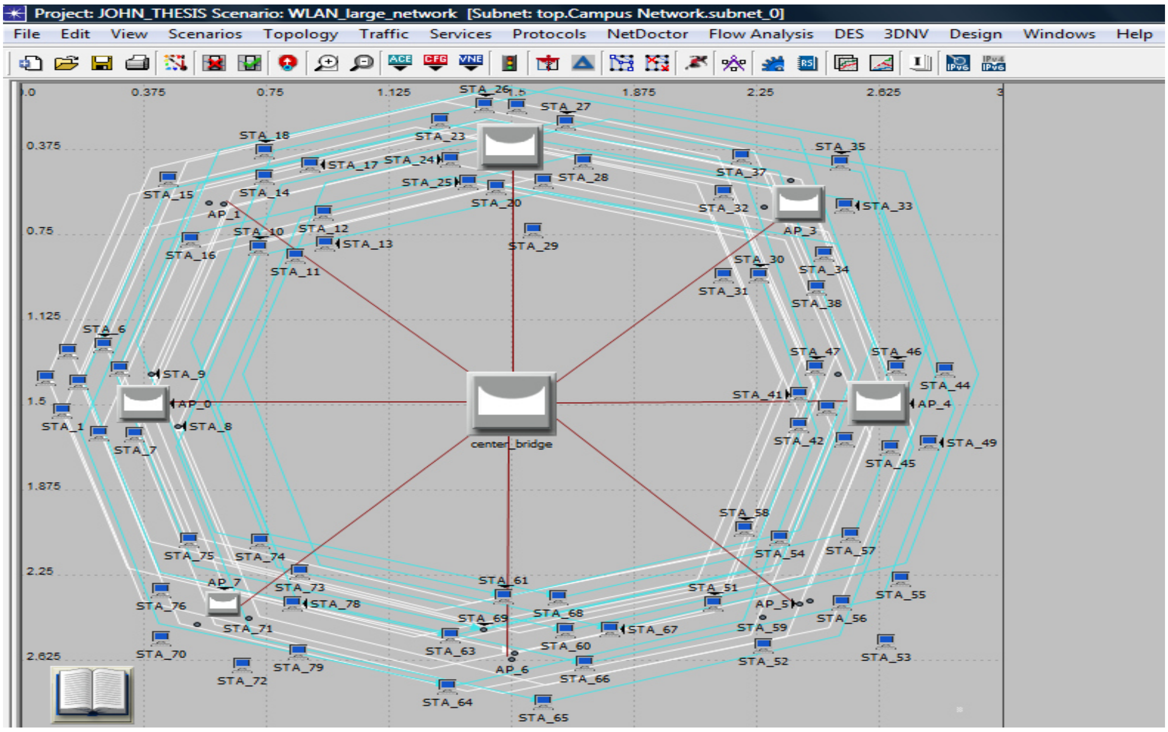

Figure 4.4: 89-node WLAN network highlighting different WLAN algorithms and features

4.4 Results and Discussion

G1: Figure 4.5

This graph compares the data traffic received by different APs in the network, namely AP_0, AP_2 and AP_3. Since the initial stations of AP_0 are mobile ones, AP_0 receives data traffic only at the beginning and then at end of simulation when its stations start their tour and come back. Additionally, it receives data traffic (around third minute) when the stations started from south visit its section and get connected to it. In contrast to AP_0, AP_2 has stable stations, so the data traffic received by it does not drop to 0 like AP_0's traffic. As expected, its received data traffic doubles when the moving stations from west and south cross its section around 60 and 120 seconds, respectively. AP_3 is visited by all moving stations at the same time. Hence, it's received data traffic is tripled when this happens around 90 seconds of simulation time.

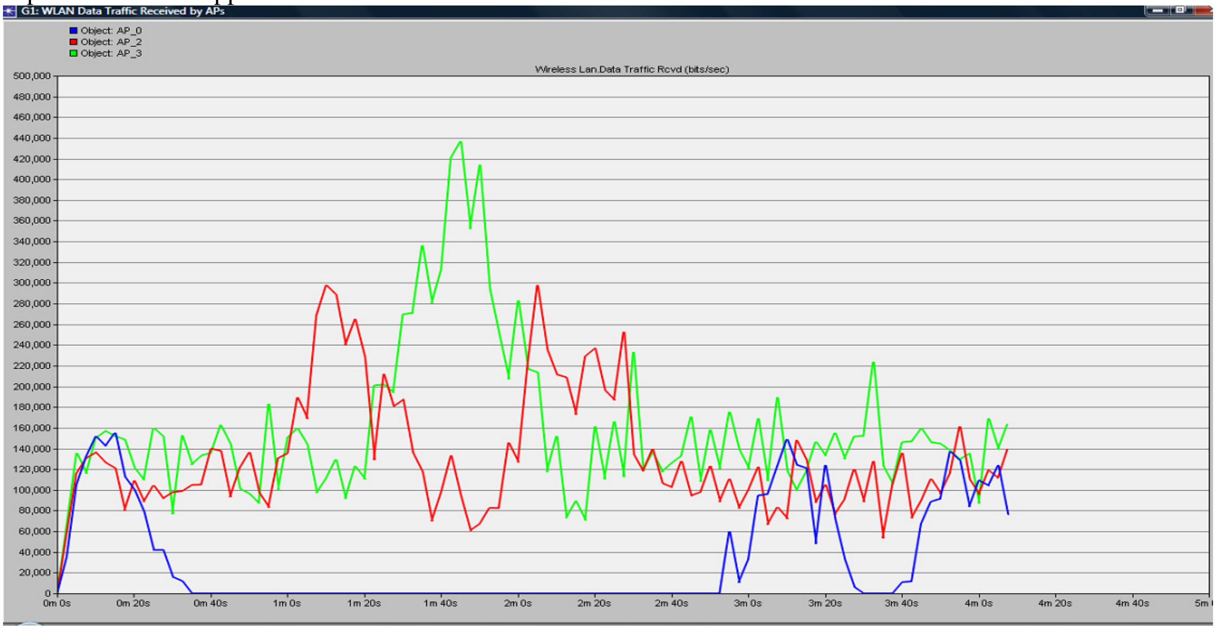

Figure 4.5: WLAN data traffic receive by APs

G2: Figure 4.6

This graph shows the media access delay measured by STA_34 during the simulation. The delay values are relatively higher from 90 seconds to 130 seconds. This is the simulation time when STA_34's BSS is visited by the moving stations. Because of tripled MAC count within the BSS, the contention gets tougher and the MAC media access delays increase.

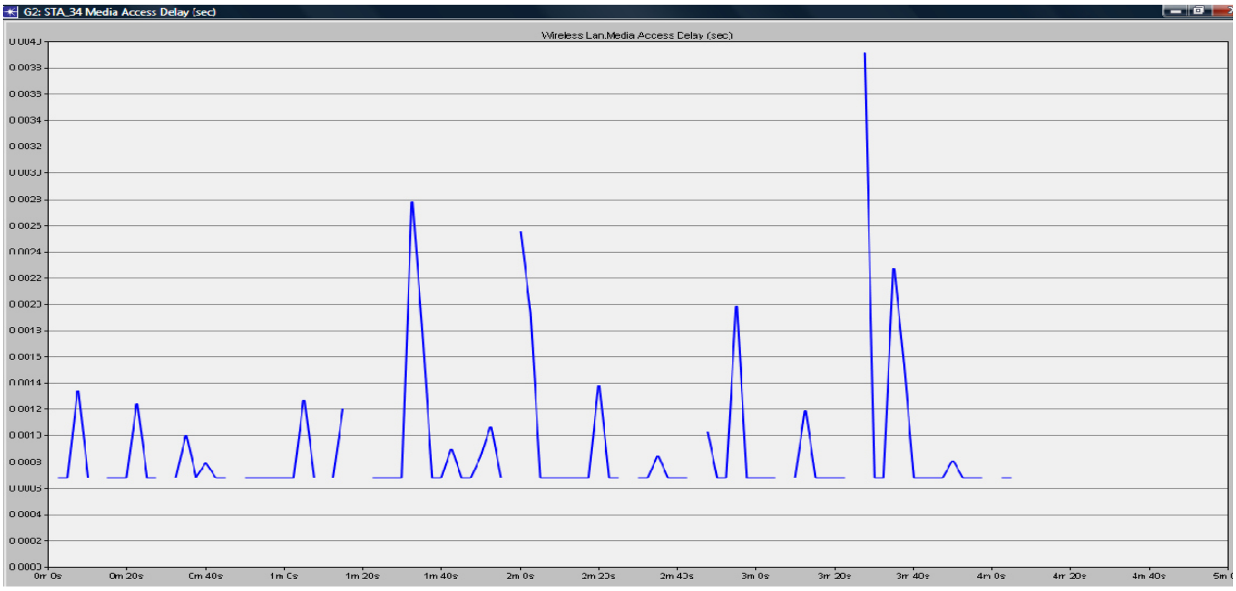

Figure 4.6: Wireless LAN media access delay

G3-G6: Figure 4.7 to 4.10.

These graphs compare STA_34 and STA_71. Both of these stations transmit its data frames at 11 Mbps. STA_34 use RTS/CTS frame exchange for every data packet, and approximately it sends 75% of its data packets as two fragments. On the other hand, STA_71 uses neither RTS/CTS messages nor data fragmentation.

Because of the usage of RTS/CTS frames, the average MAC media access delay is higher for STA_34 compared to STA_71 as also seen in G3. Due to same reason and separate acknowledgement of each fragment, control traffic received by STA_34 is much higher, which is plotted in **G4** (the temporary increase in control traffic received by STA_71 is due to by-passing of roaming stations its BSS, which use both RTS/CTS exchange and fragmentation). **G5** shows the average end-to-end delay observed by these two stations (note that stations and their APs have identical WLAN configuration) within first minute (before the visiting stations arrive). STA_71 observes a lower average for end-to-end delay, though the difference between two stations is not significant. On the other hand, if we look at all the end-to-end delay values of both stations for entire simulation in **G6**, worst case values, which are expected to happen when travelling stations also belong to the same BSS, is much higher for STA_71 compared to STA_34. This result indicates that the conservative approach followed by STA_34 pays off when there are stations entering and leaving the surrounding BSS and the contention gets tougher due to visiting stations.

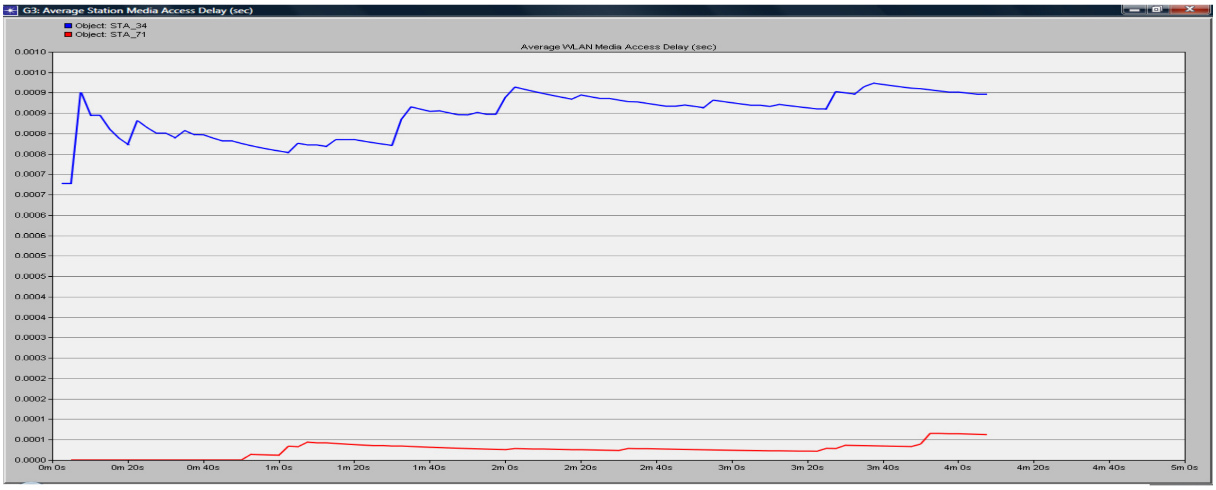

Figure 4.7: Average station media access delay

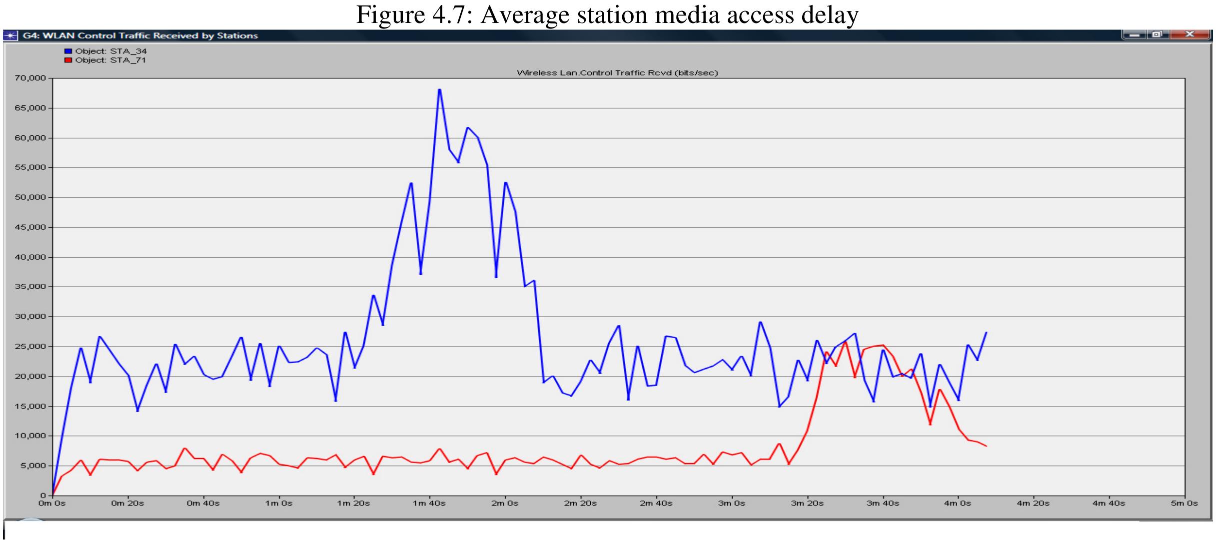

Figure 4.8: WLAN control trafic receive by states

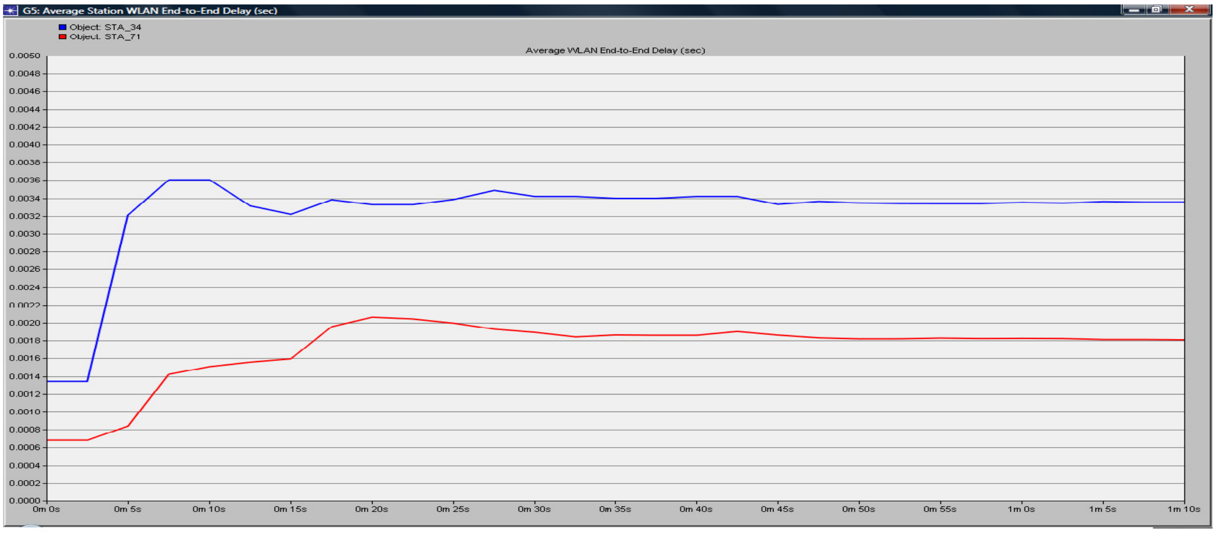

Figure 4.9: G5 Average station WLAN end-to-end delay

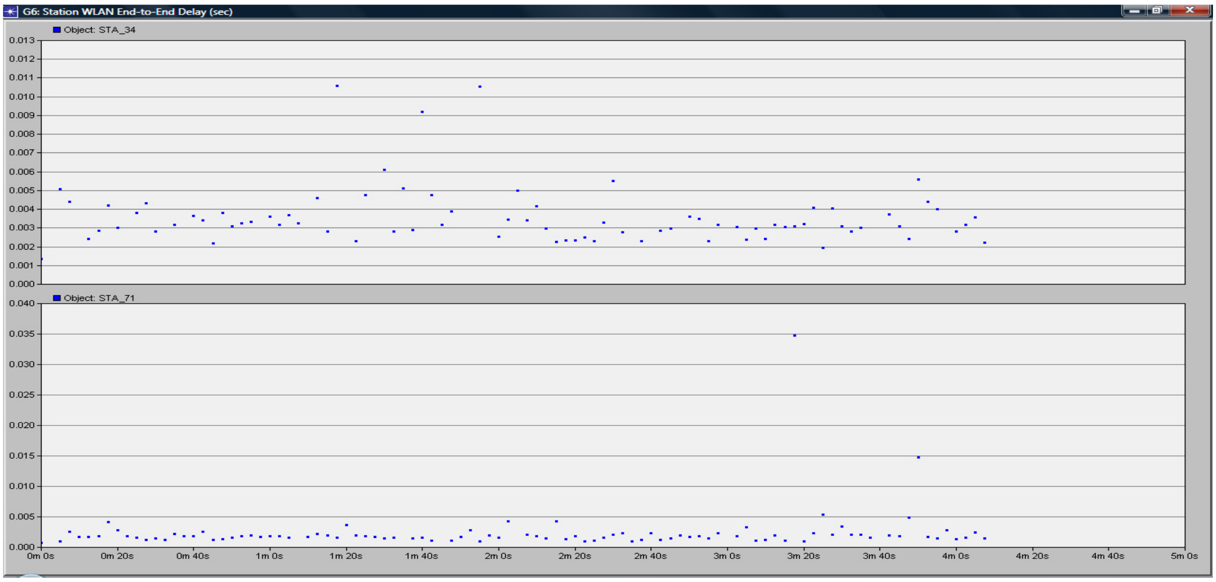

Figure 4.10: Station WLAN end-to-end delay

Communications in current deployed WSN are usually carried using the basic IEEE 802.11 DCF protocol and its optional RTS/CTS mechanism. Specially, once an event is detected, the N active reporting nodes compete to access the common data channel to report the event to the Sink. Accordingly, a host wishing to transmit a frame, first senses the channel activity until an idle period equal to Distributed Inter Frame Space (DIFS) is detected. Then, the station waits for a random back off interval before transmitting. The counter is suspended once a transmission is detected on the channel. It resumes with the old remaining back off interval when the channel is sensed idle again for a DIFS period. The station transmits its frame when the back off time becomes zero. In this case, the host starts the process by sending a RTS frame. If the frame is correctly received, the receiving host sends a CTS frame after a Short Inter Frame Space (SIFS). Once the CTS frame is received, the sending host transmits its data frame.

Table 4.2 below shows result in Idle State and Active State energy consumed by the various Stations. The network consists of a central bridge, 8 APs (access points) connected to that bridge, who's BSS IDS are set as 0 to 7 (AP_0 ...7), and 10 WLAN stations in the BSS of each AP. The stations that are in BSS 0 initially rotate in clockwise direction and complete their circle towards the end of the simulation. Hence, they are expected to get connected to all existing APs while they are traversing their trajectory each APs in counter-clockwise direction throughout the simulation. All the other stations are stable during the simulation. Table 4.2: node energy consumptions at AP_0, These parameters of station nodes are configured in the same way as they are configured for their initial APs.

There are significant are differences of consumption between the Sleep, Idle, Received and Transmit states. $P_{sl,}P_{Id}, P_{Rx}$and P_{Tx} are the powers consumed in the four states. Moreover, as the node may be asleep at packet arrival, the network latency increases. Where t_{sl}, t_{Id}, t_{Rx} and t_{Tx} are the fractions of time spent by the interface in each of the possible states: Sleep, Idle, Receive, and Transmit respectively. Increase in the time and current consumptions at each access point (APs) were observed.

Table 4.2: Node Energy Consumptions AP _0

Stations	Pm (mA/s)	Qsl (mA/s)	Qid (mA/s)	Qrx (mA/s)	Qtx (mA/s)
STA_0	0.220	0.280	0.660	1.376	2.332
STA_1	0.248	0.384	0.805	1.428	2.430
STA_2	0.219	0.273	0.744	1.728	2.365
STA_3	0.259	0.425	0.900	1.551	2.444
STA_4	0.261	0.437	0.672	1.540	2.592
STA_5	0.252	0.390	0.816	1.710	2.378
STA_6	0.266	0.435	0.759	1.599	2.565
STA_7	0.249	0.364	0.840	1.480	2.352
STA_8	0.285	0.450	1.102	1.748	2.596
STA_9	0.233	0.322	0.999	1.260	2.450

V SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

The objective of this project was to use a dynamic power management technique that considers the applications constraints to exploit active and idle states. We also simulated a wire sensor network using a protocol that can distribute the energy consumption across all nodes equally. We model Energy Consumption of the Nodes by calculating the average power (P_m) consumed by the interface and we calculated the node lifetime, which represents the time before the energy of the node reaches zero. From overall analysis of the results obtained after running the regression analysis, power management could be represented by:

$$Pm = C_0 + C_1Q_{sl} + C_2Q_{id} + C_3Q_{rx} + C_4Q_{tx} \quad . \quad . \quad . \quad (5.1)$$

5.2 Conclusion

Generally, lifetime of wireless sensor node is correlated with the battery current usage profile. By being able to estimate the power consumption of the sensor nodes, applications and routing protocols are able to make informed decisions that increase the lifetime of the sensor network. As most WSN nodes are battery powered, their lifetime is highly dependent on their power consumption. This research work studied and analyzed the effect of power management in 802.11b wireless LAN in ad- hoc mode. From the results generated, it is easy to compute the power management (Pm).

5.3 Recommendations

A critical factor of the wireless sensor network operation is the energy consumption of the portable devices. Typically, wireless nodes are battery-powered and the capacity of these batteries is limited by the weight and volume restrictions of the equipment. Consequently, it is recommended to reduce the energy consumption of the nodes in the ad hoc network. Moreover, in multi hop ad hoc networks each node may act as a router. Thus, the failure of a node due to energy exhaustion may impact the performance of the whole network.

5.4 Future Work

In order to improve on this research, some areas below ought to be explored.

a. The scope of this thesis could be improved to cover the evaluated, performance of two simple time synchronization algorithms suitable for wireless sensor networks.
b. This thesis could be expanded to reduce the time taken to send message and receive response from the WSNs and Security protocol for wireless sensor network
c. Integration of cryptographic primitives into the attributes of these WLAN models will greatly ease the evaluation of the impact of security mechanisms on the performance and energy consumption characteristics of the network as well as the entire system.

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