Green Communication Infrastructure For Vehicular Ad Hoc Network (VANET)

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Abstract: This paper deals with the design procedure of a Road Side Unit (RSU) armed with solar energy harvesting circuit and its power management module. Here, we suggest that RSUs can harvest the energy needed for its work from the surrounding environment, especially solar energy. Such suggestion permits to install RSUs in any place without considering the power supply availability and hence, extensive area is covered by the VANET infrastructure. Embedded UBICOM IP2022 platform was adopted to implement the intended Road Side Unit(RSU). A complete design steps of the electronic circuit was described and the necessary values of the system component, i.e., Solar cell panels, Battery cells and the DC to DC converter was tuned to suite the design goals. In order to decrease the power consumption of the suggested RSU and to extend the life time of the batteries, a new power management scheme we called Controlled Duty Cycling(CDC) was suggested.

Keywords: Vehicular Ad Hoc Network (VANET) , Road Side Unit (RSU), Solar Energy Harvesting, Researchable Batteries, Duty Cycling.

1.Introduction

Many research works suggest that there is a real need for a VANET infrastructure, which consists of various types of fixed nodes performing different actions according to VANET's applications demands. An important class of these nodes are Road Side Units[1-3]. Due to power supply requirements, it was recommended to localize RSUs near to wired electricity sources, such as traffic lights[4,5]. However, such placement limits the area covered by RSUs and thus, the services provided. In order to overcome this restriction, it is required to establish a self powered RSUs. In this paper, we suggest that RSUs can harvest the energy needed for its work from the surrounding environment, especially solar energy. Such suggestion permits to install RSUs in any place without considering the power supply availability and hence, extensive area is covered by the VANET infrastructure. We also suggest that these RSUs would create an *ad hoc* network in order to assist each other to deliver data packets to their destinations, that's why a suitable ad hoc routing protocol is needed. Each RSU is responsible for providing different VANET services to the vehicles in a certain area of the city, ranging from traffic safety and road monitoring services to Internet access & entertainment services. RSUs, as a part of the VANET infrastructure, receives different packets from vehicles (vehicle status or Internet access request), then forward them to the VANET server via the ad hoc network. As a member in the ad hoc network, RSU also behaves as a router in order to deliver other RSUs traffic to their destinations. From the above discussion, it is clear that RSU may be subjected to different network traffic conditions which affect seriously on their power consumption and hence their running period.

2. Related Works

VANET research has spanned a wide variety of topics in recent years. Research works related to the RSUs in the literature can be generally classified into the following categories: the vehicle-RSU data dissemination and access scheduling[1,2], the communication setup between vehicle and RSU[3,4], and the RSU placement[5-8].

D. Câmara et.al. [1] present a method to disseminate alert messages in the context of new emerging communication standards, such as LTE and Wave. The applications involving the broadcast of periodic messages, can be described using the MBMS (Multicast/Broadcast Multimedia Service). To accomplish this task a Virtual Road Side Unit (RSU) is proposed to help the authorities to reach isolated people. Also, P. Salvo et.al.[2] study the extension of the RSU coverage area via a simple data dissemination defined for urban scenarios. The proposed forwarding algorithm relies only on information local to the forwarding OBU.

In [3], the feasibility of vehicle-to-roadside communications is investigated when considering features and capabilities of the 802.11p/WAVE standard for vehicular environments. The authors expect that, by complementing advertisement repetitions from RSUs with smart piggybacking of some RSU parameters in the beacons transmitted by all vehicles (On board Units, OBUs), the RSU-awareness can be improved and RSU-OBU connection lifetimes can be lengthened. Also, T. Jiang et.al. [4] propose an V2I hybrid optimization scheme named Dynamic Resources Allocation Scheme (DRAS), in which all resources on the RSUs are scheduled as a whole and buses will be introduced as moving infrastructure points (or relay stations) to take some of the burden of the RSUs in real-time traffic conditions.

I. Filippini et.al.[5] consider the issue of distributing contents to vehicles through roadside communication infrastructure. Within this scenario, this work studies the dynamics of infrastructure deployment by using game theoretic tools. Also, T. Wu et.al[6] study the Roadside Unit (RSU) placement problem in vehicular networks. they focus on the highway-like scenario in which there may be multiple lanes with exits or intersections along the road. Also, P. Patil et.al. [7] propose a novel Voronoi network-based algorithm for the effective placement of RSU's which when deployed forms Voronoi networks in terms of the amount of delay incurred by data packets sent over the RSUs. Finally, J. Barrachina [8] propose a Density-based Road Side Unit deployment policy (D-RSU), specially designed to obtain an efficient system with the lowest possible cost to alert emergency services in case of an accident.

The energy harvesting and consumption for the RSU however, was not taken into consideration in the most prior studies as vehicles are usually assumed to have unlimited energy reserves. Moreover, from the roadside infrastructure point of view, most works assume urban settings where wired power is available at reasonable cost. It is this aspect that is considered in this paper. On the other hand, W. Shan-Hung et.al.[9] propose an energy conservative MAC layer protocol, named DSRC-AA, based on IEEE 802.11 that provides power saving to the ITS communication modules Also, our former paper[10]deals with the design procedure of a Road Side Unit (RSU) armed with solar energy harvesting circuit and its power management module. Embedded UBICOM IP2022 platform was adopted to implement the intended Road Side Unit(RSU). In order to decrease the power consumption of the suggested RSU and to extend the life time of the batteries, a central power management module based on an artificial neural network and green scheduler was suggested.

3. Characteristics of a Solar Energy Harvester

This paper focus on using solar cell energy harvesting in providing an alternative power source to supply RSUs and how to manage power provided to these devices. Solar cells have vastly differing characteristics from batteries[11-13]. The V-I characteristics of the 4-4.0-100 solar panel, which was adopted in this work, from Solar World Inc. are shown in Figure(1). The characterization was performed on different times in the year with a panel that measured 4.25" x 2.5". Solar panels are characterized by two parameters, the open circuit voltage (V_{oc}) and the short circuit current (I_{sc}). These form the x- and y- intercepts of the V-I curve, respectively[14-15]. Several observations can be made from the figure:

- First, it is clear that a solar panel behaves as a voltage limited current source (as opposed to a battery which is a voltage source), see Figure(1a).
- Second, there exists an optimal operating point at which the power extracted from the panel is maximized, see Figure(1b).
- As the amount of incident solar radiation decreases (or increases), the value of I_{sc} also decreases (or increases). However, V_{oc} remains almost constant. Due to its current source-like behavior, it is difficult to power the target system directly from the solar panel, since the supply voltage would depend on the time varying load impedance. Hence, an energy storage element, such as a battery, must be used to store the energy harvested by the panel and provide a stable voltage to the system.
- Finally, the amount of the electrical current produced by the solar cell panels depends mainly on the number of parallel connected cells, the weather conditions and the day time (effective charging time) period, see Figure(1c & 1d).

4. Harvesting Circuit Design

One of the goals in this paper is to design an efficient ,simple and adaptable energy harvesting module which can be used with different types of embedded RSUs. Although, UBICOM IP2022[16] was selected to be the intended RSU, the suggested energy harvesting circuit can be slightly modified to work with other embedded devices. The core of the harvesting module is the harvesting circuit, which draws power from the solar panels, manages energy storage, and routes power to the target system, see Figure(2). The most important consideration in the design of this circuit is to maximize efficiency. A DC-DC converter is used to provide a constant supply voltage to the embedded system. The choice of DC-DC converter depends on the operating voltage range of the particular battery used, as well as the supply voltage required by the target system. If the required supply voltage falls within the voltage range of the battery, a boost-buck converter is required, since the battery voltage will have to be increased or decreased depending on the state of the battery. However, if the supply voltage falls outside the battery's voltage range, either a boost converter or a buck converter is sufficient, which significantly improves power supply efficiency. In this work, we used Texas Instruments TPS63000 low power boost-buck DC-DC Converter[17] because it suits our needs. The solar panel is connected to a battery whose terminal voltage determines the panel's operating point along its V-I curve. We ensure operation at the maximal power point through our choice of battery. Using two parallel AA battery cells with voltage varies between 2.9V and 3.1V, which ensures that the voltage across the solar panel terminals remains close to optimal. To avoid problems such as decreased radio range caused by decreased battery voltage, we use a step up DC-

DC converter to provide a constant 3V supply voltage to the battery which provides overcharge and undercharge protection for the batteries[17].

5. Investigation of Power Requirements of UBICOM IP2022 Network Processor:

In order to implement a functional and an efficient Road Side Unit(RSU), a networked, embedded in nature, robust and programmable device is required, many options are available from different vendors. Due to its versatile features, embedded UBICOM IP2022 platform was chosen in this paper to implement the intended Road Side Unit(RSU). As a road side unit, it receives different packets from the vehicles and other RSUs and forward them via multi hop Ad Hoc network to its control center.

UBICOM IP2022 is a network processor produced by UBICOM Company and provides the whole solution as a fully integrated platform - the Real Time Operating System (RTOS), the protocol stack, and the necessary hardware. The same device can supports Ethernet, Bluetooth wireless technology, IEEE 802.11, and so on. The key to this approach is Software System on Chip (SOC) technology as shown in Figure(3) [16].

An experimental network setup was used to perform several tests in order to determine the power requirements of UBICOM IP2022 platform, see Figure(4).

The experimental network consists of an ordinary PC supplied with Belkin Dual-Band Wireless PCMCIA Network Card F6D3010 working at different data rates, IP2022 Ubicom platform was also supplied with the same WLAN NIC, the energy harvesting module and a real time storage oscilloscope. PC1was programmed to be a traffic generator to send and receive a 1Mbps streamed UDP traffic to and from the IP2022 Ubicom platform. The real time oscilloscope Tektronix224 was used to measure the drained current from the batteries according to the different network traffic conditions. One of its channels was used to measure the voltage across a (0.1Ω) resistor, which is proportional to the drained current. The measured samples were ordered and sent to PC1 via an RS232 connection. The objective of this experiment is to record the current drained by the RSU according to its different modes of operation: Transmission, Reception, IDLE , CPU full load and SLEEP. Table(1) summarize the settings of this experiment while Table(2) lists the average values obtained for different data rates.

Table(1): Network Setup

Experiment duration in each Case (Minute)	5
WLAN NIC	Belkin PCMCIA Network Card F6D3010
Supply Voltage(v)	3
RF power (W)	1 dBm
WLAN Packet length (Byte)	1500
Packet/sec.	84

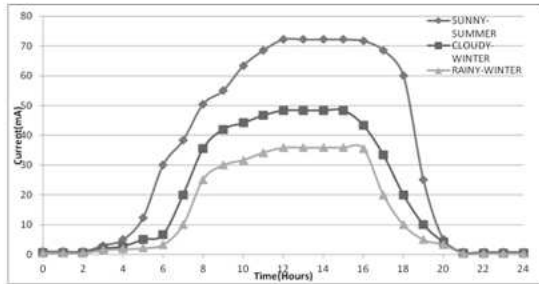Table(2): Measured Current Values

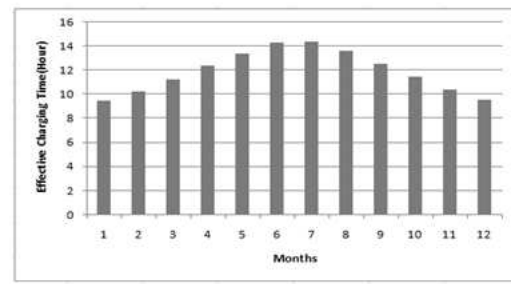| Current drained in TX mode(mA)	150(for IEEE802.11a)
Current drained in RX mode(mA)	120(for IEEE802.11a)
Current drained in IDLE mode(mA)(WLAN NIC disconnected)	100
Current drained in CPU full load mode(mA)(WLAN NIC disconnected)	150
Current drained in SLEEP mode(mA)(for the Ubicom board only)	1
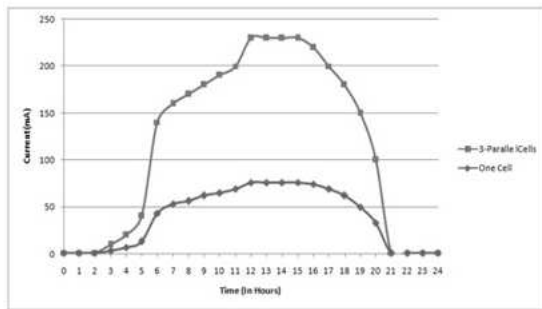
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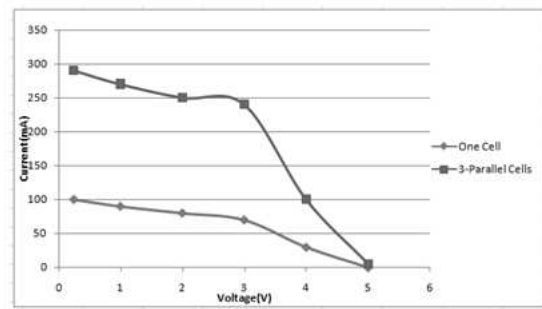
(b)

(c)

(d)

Figure(1); Measured characteristics of the Solar World 4-4.0-100 solar panel: (a) Produced current variation during one day (b) V-I Curve (c) Produced current variation a solar panel in different weather conditions (d) Effective charging time/month
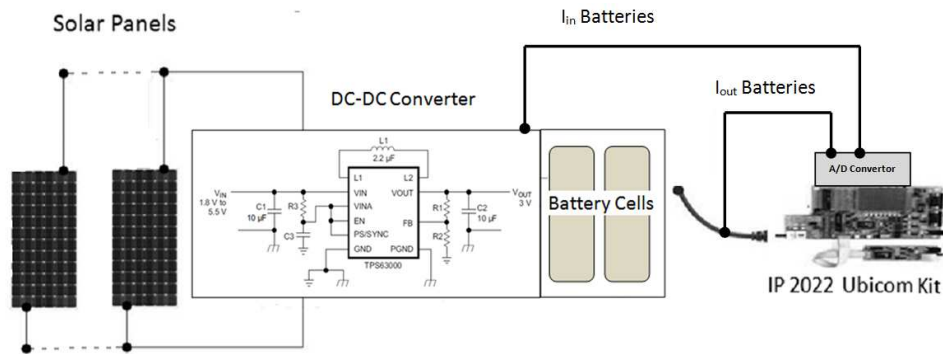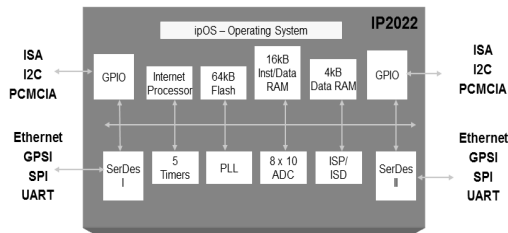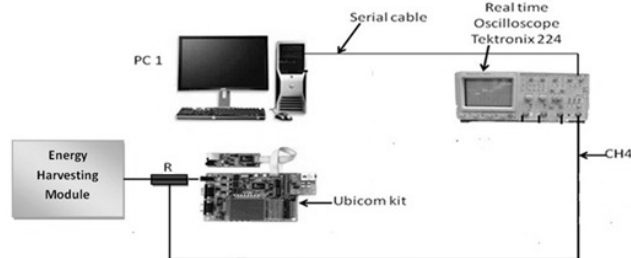

Figure (2); Application Circuit for Solar Energy Harvesting Module


Figure(3); IP2022 Block Diagram

Figure(4); The Experimental Network Setup

As expected, the maximum current drained was when working in the transmission mode, while the reception mode requires less current. Ubicom board measurements were performed after disconnecting the WLAN NIC and the drained current was observed in three cases: IDLE mode(CPU utilization is 0%), when CPU is fully loaded(CPU utilization is 100%) and SLEEP mode (explained later).

6. Research Methodology

In order to evaluate the power consumption of the intended Ubicom RSU under realistic road traffic condition, a simulation model was built using the Network Simulation package. The goal of building this model is to generate a traffic patterns as close as possible to the real situations. The first step is to choose a real road map in which the RSUs will be installed (i.e., the network topology), see Figure(5).
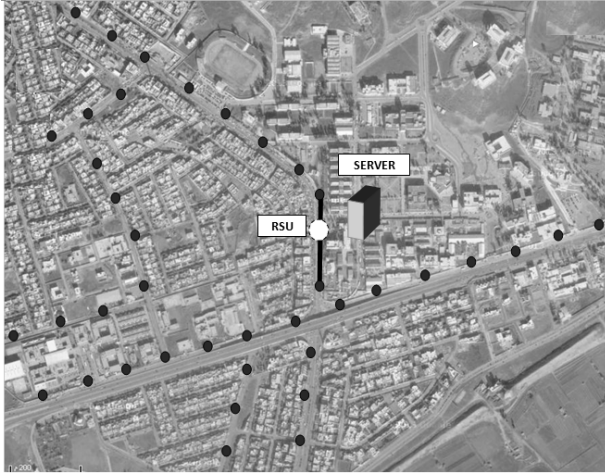
Figure(5); VANET Topology

Our network represents an Vehicular Ad hoc Network infrastructure of 40 RSU covering (5x5 Km) area of Mosul city/Iraq. The data traffic generated by the RSUs (as a result to their interaction with the vehicles and other RSUs) are forwarded using suitable routing protocol to a central server. It was assumed that vehicles broadcast their 100 byte status packets each one second[3], while RSUs generate their 1000 byte traffic report 10 times per minute and forward them to the central server(using File Transfer Protocol (FTP))[3]. As a result of our earlier analysis [18], Optimized Link State Routing (OLSR) gives the best performance compared to other ad hoc routing protocols when working in non-stationary ad hoc topology, so that it was adopted in our simulation model. OLSR is a *proactive link-State* routing protocol designed for *ad hoc* networks which show both low bandwidth utilization and low packet delay. OLSR is a type of classical link-state routing protocol, which relies in employing an efficient periodic flooding of control information using special nodes that act as *multipoint relays* (MPRs). The use of MPRs reduces the number of required transmissions [19]. OLSR daemons periodically exchange different messages in order to maintain the topology information of the entire network. The core functionality is performed mainly by using three different types of messages: HELLO, TC (topology control), and MID (multiple interface declaration) messages. The OLSR mechanisms are regulated by a set of parameters predefined in the OLSR RFC 3626 [19] which was used in our simulation model, see Table (3).

In order to simplify our simulation model, RSUs were

traffic conditions shown in Figure(6). Traffic volume statistics were collected for a three lanes street in Mosul city/Iraq in front of a shopping center and bypasses Mosul University Campus. Usually, the traffic data volume is represented by a time series which is a sequence of time ordered data values that are measurements of a physical process. In this particular study, the traffic volume (i.e. number of vehicles passed) are collected every five minutes. With a five minute time interval the data oscillates too much, and the random part is high. Therefore, it is necessary to aggregate them to fifteen minute intervals. The mean value is built with three values. To obtain a smooth time curve, an average of three values can be computed. It is clear that each road has its own traffic volume distribution over time according to the users behavior and their needs. This caused that RSUs installed in each road to has its own power requirements according to the traffic demands caused by the variance of the road traffic volume.

Our simulated network was tested with the presence of different VANET services as listed in Table(4). These services creates different network traffic profiles according to users demands. Different scenarios were built to determine the effect of different network parameters on the network traffic and hence, RSU power consumption. It is worthwhile to mention that although VANET services and protocols are still undefined and under development, we make use of the traditional HTTP, FTP and Video Streaming protocols to create network conditions as close as possible to the real one and hence the required stress on the RSUs.

Table(3): Simulation Model Parameters

|	
Simulation Time (Minute)	60
No. of RSUs	40
Network Span Area (Km²)	25 (5 Km x 5 Km)
Distance between RSUs (Km)	1
Vehicles to RSU Packet Length (Byte)	100
Vehicles to RSU Packets Rate (Packet/sec.)	1
RSU to Server Packet Length (Byte)	1000
RSU to Server Packets Rate (Packet/Minute)	10
RSU Modeling Parameters	Packets Processing Rate (Packet/sec.) = 2000 Memory (Byte) = 2 M
WLAN settings	Data Rate (Mbps) 18 for IEEE802.11a
OLSR settings	Hello Interval(sec.) = 2 TC Interval(sec.) = 5 Neighbor Hold Time(sec.) = 6 Topology Hold Time(sec.) = 15 Duplicate Message Hold Time(sec.) = 30
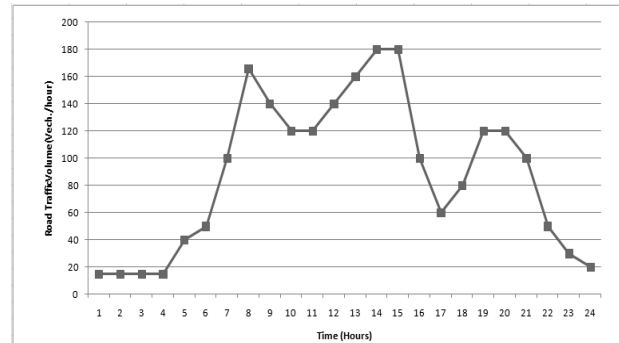
Figure(6); Road Traffic Statistics

Table (4): Traffic Profiles of the Simulated VANET

| Traffic Profile	Applications	Description
1	Traffic Safety & Monitoring Application	Vehicle to RSU packet Length = 100 Byte Vehicle to RSU packets Rate = 1 Packet/s RSU to Server Packet Length = 1000 Byte RSU to Server Packets Rate = 10 Packet/Minute
2	Traffic Safety & Monitoring Application	Vehicle to RSU packet Length = 100 Byte Vehicle to RSU packets Rate = 1 Packet/s RSU to Server Packet Length = 1000 Byte RSU to Server Packets Rate = 10 Packet/Minute
	Light Web Browsing	HTTP Protocol Page Inter-request interval = 60 s No. of Objects = 6 Object Size = (500 to 2000)Byte [Uniformly Distributed]
3	Traffic Safety & Monitoring	Vehicle to RSU packet Length = 100 Byte Vehicle to RSU packets Rate = 1 Packet/s RSU to Server Packet Length = 1000 Byte RSU to Server Packets Rate = 10 Packet/Minute
	Heavy Web Browsing	HTTP Protocol Page Inter-request interval = 30 s No. of Objects = 8 Object Size = (2000 to 10000)Byte [Uniformly Distributed]
4	Traffic Safety & Monitoring	Vehicle to RSU packet Length = 100 Byte Vehicle to RSU packets Rate = 1 Packet/s RSU to Server Packet Length = 1000 Byte RSU to Server Packets Rate = 10 Packet/Minute
	Heavy Web Browsing	HTTP Protocol Page Inter-request interval = 30 s No. of Objects = 8 Object Size = (2000 to 10000)Byte [Uniformly Distributed]
	File Transfer	File Transfer Protocol (FTP) File Size = 1 MByte Inter-request Interval = 60 s
5	Traffic Safety & Monitoring Application	Vehicle to RSU packet Length = 100 Byte Vehicle to RSU packets Rate = 1 Packet/s RSU to Server Packet Length = 1000 Byte RSU to Server Packets Rate = 10 Packet/Minute
	Heavy Web Browsing	HTTP Protocol Page Inter-request interval = 30 s No. of Objects = 8 Object Size = (2000 to 10000)Byte [Uniformly Distributed]
	File Transfer	File Transfer Protocol (FTP) File Size = 1 MByte Inter-request Interval = 60 s
	Video Streaming & advertisement	128 Kbps Constant Bit Ratio(CBR)-Compressed Video.
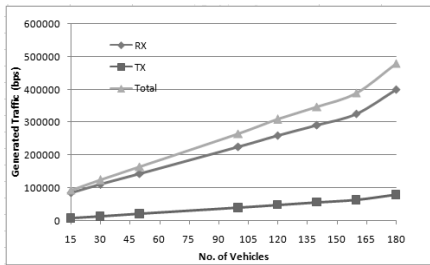
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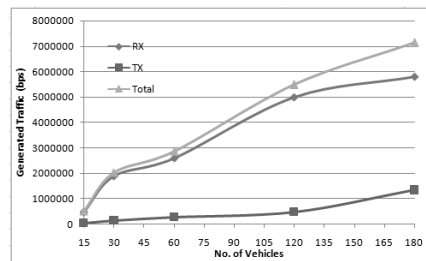
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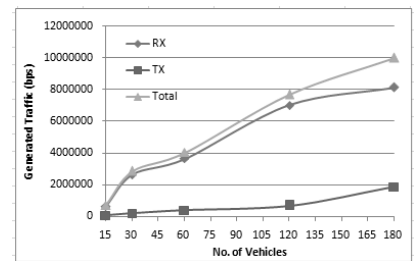
(c)
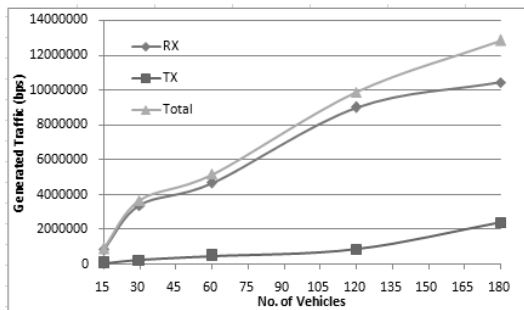
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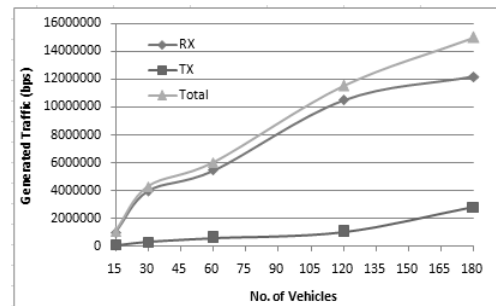
(e)

Figure(7); VANET Traffic (a)Traffic Profile1 (b)Traffic Profile2 (c)Traffic Profile3 (d)Traffic Profile4 (e)Traffic Profile5

The effect of varying the number of served vehicles (by each RSU) on the generated network traffic was studied. Five traffic profiles were tested with the presence and absence of different network applications in addition to the road traffic monitoring service. According to the users behavior recorded by [20], it was assumed that 35% of the total vehicles were involved in acquiring the various VANET services. From Figure(7), it is noted that increasing the number of vehicles add more traffic to the system (especially received traffic). Also, multiple applications VANET consumes much higher bandwidth. The shown network traffic was originated from different protocols in the TCP/IP stack. The major contributor was the application layer traffic in both directions (sent & receive) while other traffic sources such as layer2 packets and OLSR related traffic have much less effect. It is useful to mention that RSU location in the ad hoc network affects seriously on their network traffic and the highest traffic (higher power consumption) was observed in the RSUs nearer to the central server as shown in Figure(5). These RSUs were selected in our experimental model as they represents the worst possible case (from power consumption point of view).

7. Experimental Work

In this section, the different network traffic patterns generated from running the previous simulation model were used in our experimental network. The experimental network consists of 2 ordinary PCs supplied with Belkin Dual-Band Wireless PCMCIA Network Card F6D3010 working at IEEE802.11a-18 Mbps, IP2022 Ubicom platform having the same WLAN NIC, the energy harvesting module and a real time storage oscilloscope. The experimental work steps can be explained as follows:

1. PC1was programmed to be a traffic generator to emulate the behavior of the vehicles and other RSUs, which forward their traffic packets to the Ubicom platform. The (RX) network traffic pattern shown earlier in Figure(7) was considered to generate the network traffic (in bit/s), meanwhile Ubicom generate the (TX) traffic of the same Figure.

2. PC2 is considered to be the road traffic monitoring server and represents the destination in which all the Ubicom traffic is forwarded.

3. The real time oscilloscope Tektronix224 was used to measure the drained current from the batteries according to the different network traffic conditions. One of its channels was used to measure the voltage across a (0.1Ω) resistor, which is proportional to the drained current. The measured samples were ordered and sent to PC2 via an RS232 connection.

4. Ubicom platform receives different packets from PC1(RX traffic), stores them temporally in its 2MByte external memory, then after performing the necessary processing it send them out to PC2 as a transmitted traffic(TX traffic).

As mentioned earlier, the goal is to generate a realistic network load (as close as possible to the actual circumstances) while measuring the drained current by the Ubicom (RSU) resulting from this network conditions. Our tests includes measuring two quantities:

1. Current drained in Normal Mode: In this mode the Ubicom board and its accessories are working without any power management.

2. Current drained in Sleep Mode: In this paper, we suggest a new power management scheme we called Event Driven Duty Cycling(EDDC).

Traditionally, power management protocols used for Wireless Sensor Networks (WSN) can be implemented either as independent sleep/wakeup protocols running on top of a MAC protocol (typically at the network or application layer), or strictly integrated with the MAC protocol itself [21]. Unlike the Wireless Sensor nodes, RSUs must always be ready to receive different packets and cannot be turned OFF entirely. It was noted from the earlier results that Ubicom board spends some of its time is IDLE mode, so that it will be useful to send it to SLEEP mode to save power. The suggested Event Driven Duty Cycling(EDDC) technique makes use of an important feature in Ubicom board named "Clock Stop Mode"; in which the system clock may be disabled which disables the CPU core clock and hence, the Ubicom board. When the system clock is disabled, the interrupt logic continues to function, and a Sleep timer may be enabled to keep running. Recovery from clock stop mode (Sleep Mode) to normal execution is possible using Sleep timer interrupts or in response to an external interrupt form WLAN NIC. This method do not reset the chip, so program execution continues from where it was stopped. This mode sends the Ubicom board only (WLAN NIC is still ON) to power saving mode in which its circuitry (except the External interrupts circuits and the program memory) goes OFF. Whenever an interrupt occurs (due to the reception of a packet by the WLAN NIC), the board wakes up within 3 clock cycles (25 ns) to perform the necessary actions.

In order to investigate the daily power consumption of an RSU, we make use of the road traffic patterns in Figure(6) to generate a network traffic as a function of the number of served vehicles and the VANET applications, see Figure(8). It is clear that the amount of current drained from the RSU varies as road traffic volume(No. of served vehicles)changed over time. Also, Multiple VANET applications have great influence on the drained current because (more network traffic-more RSU processing) is required in order to respond to user needs.
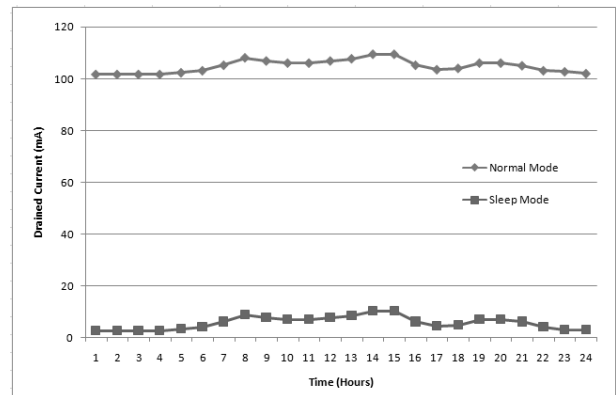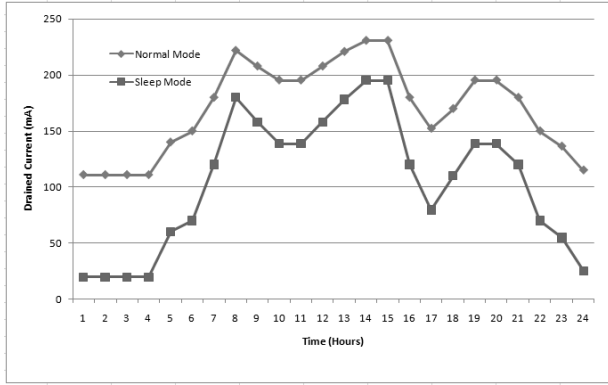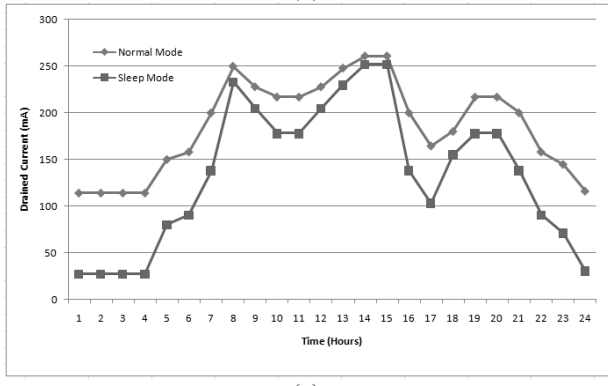

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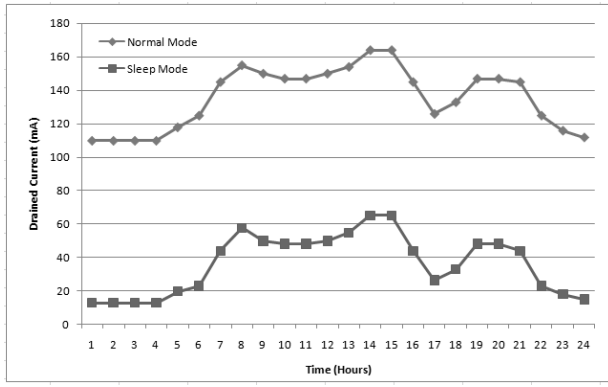
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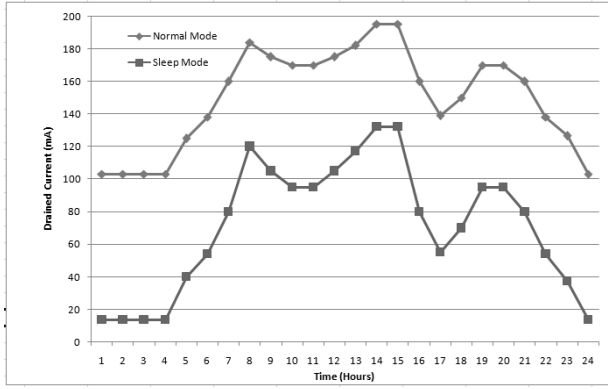
(c)

(d)

(e)

Figure(8); Current Drained From Ubicom Platform
(a)Traffic Profile1 (b)Traffic Profile2 (c)Traffic Profile3
(d)Traffic Profile4 (**e**)Traffic Profile5

Also, it is clear from Figure(9) that the effectiveness of the proposed EDDC technique diminishes as the load offered to the network increases due to the decrement in the IDLE periods and hence, RSU working in SLEEP mode consumes more power closer to the Normal mode.
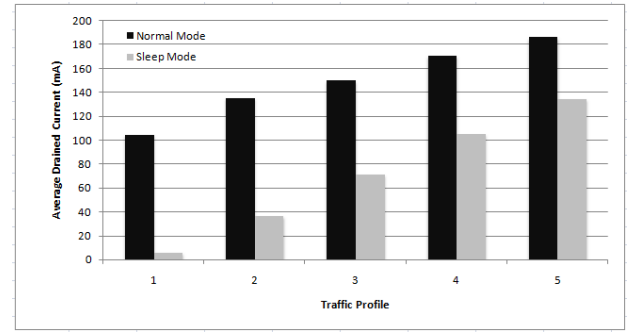
Figure(9); Average Current Drained From Ubicom Platform According to Different Traffic Profiles

8. Controlled Duty Cycling (CDC) Technique

As shown earlier in Figures(8 & 9), although RSU working according to the suggested EDDC technique consumes less power, it is still suffering from a stability problem. This technique became less efficient as the load applied to the network increases, so that, we need a control mechanism on the Sleep period (i.e., the Duty Cycle) in response to the different network conditions. In this paper, we suggest that RSU should perform according to its available energy, specifically, the service rate of the RSU is determined as a function of the RSUs' power budget. In this case we need to derive a relation among Duty Cycling periods, Average Service Rate (ASR) and the Available Energy(AE). We firstly start by defining the following terms:

- Average Service Rate (ASR) is the average of total traffic (in bps) transmitted and received from/to the RSU.
- Duty Cycling Periods: In this paper, time is divided into (1 s) slots. Hence, Duty Cycle is the ratio of the sleep periods to the total slot time.
- Available Energy (AE) is the summation of the residual energy in the batteries from the last day plus the expected energy in the next day.

Our approach involves the following steps, see Figure(10):
1. In the beginning of each *working day*, RSU calculates the Available Energy (AE) as follows:

$$AE = RE + EE \qquad (1)$$

Where:
RE is the Residual Energy from the last day
EE in the Expected harvested Energy in the current day

RE of the batteries can be found as:

$$RE = (\text{Initial Energy} + I_{in} \times \text{Effective Charging Time}) - I_{out} \times 24 \quad (2)$$

It is obvious that in order to calculate RE, RSU needs to measure the current flowing to/from the batteries(I_{in} & I_{out} respectively) during the whole working day. We make use of the Ubicom's integrated 12 bit A/D convertor to achieve this task as shown earlier in Figure(2). Our measurement process involves taking a sample every one second, then calculating the average current values in each hour. Effective Charging Time was shown earlier in Figure(1d) and represents the number of hours in which the current drained from the solar panels is greater than zero.

In order to estimate the value of EE, we suggest that the control center should broadcast (to all RSUs) the weather forecasts and the effective charging time for this particular day. This weather report includes the expected weather (Sunny, Cloudy or Rainy) and the number of useful charging hours. As shown earlier in Figure(1c), our measurements indicates that the highest current could be acquired in sunny

the maximum current in rainy days. As a function of current measurement procedure mentioned earlier, RSU can determine the current value expected according to its historically recorded current values in a similar weather conditions, and hence, EE could be calculated as:

$$EE = \text{Average Expected Current} \times \text{Effective Charging Time} \quad (3)$$

2. The next step is to calculate the Average Service Rate (ASR) of the RSU in this particular day according to the value of AE. The relation between Service Rate (SR) and AE could be derived by determining the power consumed according to RSU activities as follows:

$$AE = E_{TX} + E_{RX} + E_{Proc.} + E_{Sleep} \quad (4)$$

E_{TX}, is the energy consumed during data transmission and can be expressed as:

$$E_{TX} = I_{TX} \times \text{bit time during transmission} = SR(I_{TX}/n \times \text{Data Rate}) \quad (5)$$

E_{RX}, is the energy consumed during data reception and can be expressed as:

$$E_{RX} = I_{RX} \times \text{bit time during reception} = SR(I_{RX} \times (n-1)/n \times \text{Data Rate}) \quad (6)$$

$E_{Proc.}$ is the energy consumed during data processing and can be expressed as:

$$E_{Proc.} = SR (I_{Proc.}/\text{Data Processing Speed of the RSU}) \quad (7)$$

E_{Sleep} is the energy consumed during Sleep mode and can be expressed as:

$$E_{Sleep} = SR((I_{Sleep} \times \text{Data Processing Speed} - I_{Sleep})/ \text{Data Processing Speed}) \quad (8)$$

Now, the final relation between AE and the Service Rate (SR) can be expressed as:

$$SR = (AE - d) / (a + b + c - e) \quad (8)$$

Where:
$a = (I_{TX}/n \times \text{Data Rate})$
$b = (I_{RX} \times (n-1)/n \times \text{Data Rate})$
$c = (I_{Proc.}/\text{Data Processing Speed of the RSU})$
$d = I_{Sleep} \times 24$
$e = (I_{Sleep} / \text{Data Processing Speed})$

Finally, ASR could be calculated as:

$$ASR = 0.5 \, SR \quad (9)$$

3. The next step, is the mapping procedure of ASR value to suit the different rates of the applied load. ASR represents the service rate for middling number of vehicles, so that mapping is necessary in order to afford variable service rate according to the variation in the number of vehicles. This step requires that RSU has the ability to *predict* the future load according to its historical behavior. Our prediction algorithm actually makes use of an artificial neural predictor, which is a three-layer neural network predictor has 20 network inputs where external information is received, and one output layer with one unit where the solution is obtained. The network input and output layers are separated by one hidden layer composed of 10 units. The connections between the units indicate the flow of information from one unit to the next, i.e., from left to right. In order to make meaningful predictions, the neural network needs to be trained on an appropriate data set. Basically, training is a process of determining the connection weights in the network. The final goal is to find the weights that minimize some overall error measure, such as the sum of squared errors or mean squared errors. We have developed a neural predictor and performed experiments to prove its accurate prediction ability with low overhead suitable for dynamic real time settings similar to this system model. Our 20:10:1 network with a learning rate of 0.25 has reduced the mean and standard deviation of the prediction errors by approximately 65% and 73%, respectively. The network needs a 30 minutes to be trained with 1000 samples, and designed to predict the traffic volume given the past four values of the time series. A set of 1000 consecutive 15 minute samples was extracted from the data available. This is the volume of 10 days. The set was divided in a training set (4 /7 days of week) and a test set (2 /7 days of week). The model generates a forecast for the next 24 hour period from the daily traffic profile. The network was extended for the whole set of data, and the results were quite satisfactory. The comparison of the original traffic volume with the neural network predicted values for 24 hours show them in close agreement. Evaluation of the model performance can be done by the *Mean Square Error*, calculated as the difference between forecasted and actual demand. The average errors for the forecasting up to 24 hours are about 0.007.

4. The last step is to calculate the Sleep period in each time slot (i.e., 1s). Average Sleep Period (ASP) can be found easily using the following eq.:

$$\text{Average Sleep Period} = 1 - (ASR/\text{Data Rate}) \quad (10)$$

The same mapping procedure mentioned earlier is applied to calculate the different values of sleep periods according to the variation in the applied network load.

5. After performing the above calculations, RSU can begin its work safely. As each time slot is divided into Active and Sleep periods, Ubicom's enters the sleep period first. At the same time, different types of data packets are accumulated in the WLAN NIC buffers(which is still ON). When Active period starts, Ubicom board wakes up and begin to process the packets received from its WLAN NIC, see Figure(10).
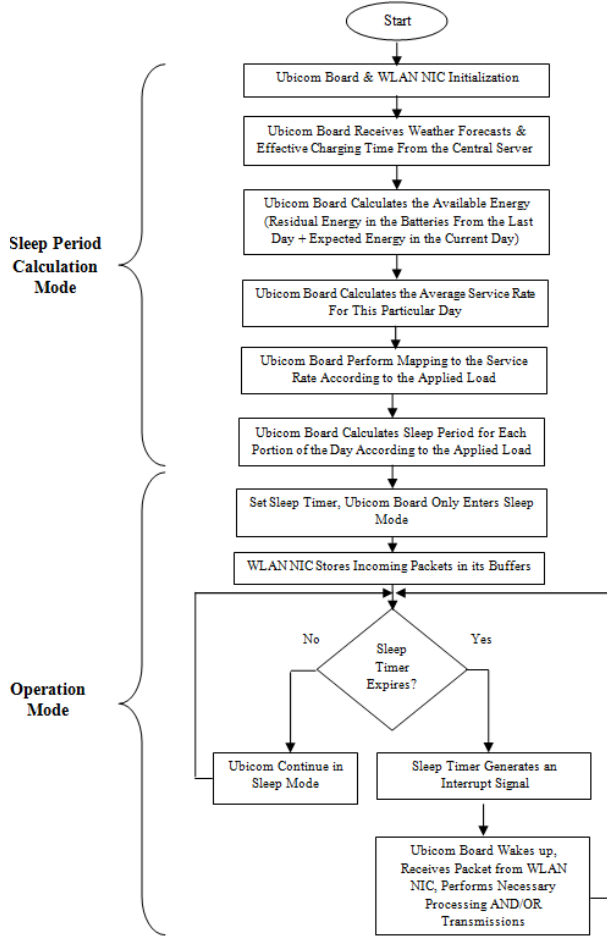
Figure(10): Controlled Duty Cycling (CDC) Technique

9. Implementation Scenarios of CDC Technique

In this section, CDC technique was implemented in different scenarios. The initial settings of these experiments could be found in Table(5). The Purpose of these experiments is to examine the ability of the suggested CDC method to adapt against different working conditions wherein different Available Energy (AE) levels were assumed. Table(6) lists the different values of ASR and ASP obtained from these scenarios, where Residual Energy (RE) stands for the battery charging percentage and (N) is the number of paralleled solar panels.

Table (5) Initial settings of CDC experiments

| Data Rate	18 Mbps (IEEE802.11a)
Traffic Characteristics	Traffic Profile 5 n = (RX Traffic/TX Traffic)= 4
Data Processing Speed of the RSU	24 Mbps From Ref.[16]
I_{TX}	150 mA
I_{RX}	120 mA
$I_{Proc.}$	150 mA
I_{Sleep}	1 mA
Battery Characteristics	3 v, 2800mAh
Solar Panel Dimensions	4.25" x 2.5"
Average Current Produced in Sunny Day Effective Charging Time	34 mA 15 Hours
Average Current Produced in Cloudy Day Effective Charging Time	20.5 mA 13 Hours
Average Current Produced in Rainy Day Effective Charging Time	14.4 mA 11 Hours

Table (6) ASR & ASP Values Under Different Conditions

| RE (mAh)	N	Weather Condition	AE (mAh)	ASR (Mbps)	ASP (s)
100%	1	Sunny	3310	5.171875	0.712674
100%	1	Cloudy	3066.5	4.791406	0.733811
100%	1	Rainy	2958.4	4.6225	0.743194
100%	3	Sunny	4330	6.765625	0.624132
100%	3	Cloudy	3599.5	5.624219	0.687543
100%	3	Rainy	3275.2	5.1175	0.715694
100%	6	Sunny	5860	9	0.5
100%	6	Cloudy	4399	6.873438	0.618142
100%	6	Rainy	3750.4	5.86	0.674444
75%	1	Sunny	2610	4.078125	0.773438
75%	1	Cloudy	2366.5	3.697656	0.794575
75%	1	Rainy	2258.4	3.52875	0.803958
75%	3	Sunny	3630	5.671875	0.684896
75%	3	Cloudy	2899.5	4.530469	0.748307
75%	3	Rainy	2575.2	4.02375	0.776458
75%	6	Sunny	5160	8.0625	0.552083
75%	6	Cloudy	3699	5.779688	0.678906
75%	6	Rainy	3050.4	4.76625	0.735208
50%	1	Sunny	1910	2.984375	0.834201
50%	1	Cloudy	1666.5	2.603906	0.855339
50%	1	Rainy	1558.4	2.435	0.864722
50%	3	Sunny	2930	4.578125	0.74566
50%	3	Cloudy	2199.5	3.436719	0.809071
50%	3	Rainy	1875.2	2.93	0.837222
50%	6	Sunny	4460	6.96875	0.612847
50%	6	Cloudy	2999	4.685938	0.73967
50%	6	Rainy	2350.4	3.6725	0.795972
25%	1	Sunny	1210	1.890625	0.894965
25%	1	Cloudy	966.5	1.510156	0.916102
25%	1	Rainy	858.4	1.34125	0.925486
25%	3	Sunny	2230	3.484375	0.806424
25%	3	Cloudy	1499.5	2.342969	0.869835
25%	3	Rainy	1175.2	1.83625	0.897986
25%	6	Sunny	3760	5.875	0.673611
25%	6	Cloudy	2299	3.592188	0.800434
25%	6	Rainy	1650.4	2.57875	0.856736

It is noted that the suggested CDC technique was able to adapt its performance according to the available energy levels and hence continue to function in a pre-managed and planned manner. Figure(11) shows the daily behavior of the RSU while tracking the load offered by its associated vehicles and other RSUs. This Figure was plotted by mapping the ASR (the service rate for an *average* number of vehicles) to be adjusted in response to the number of the daily served vehicles as shown earlier in Figure(6).

(a)

(b)

(c)

(d)
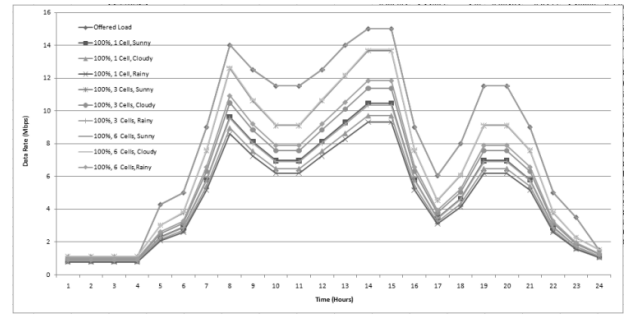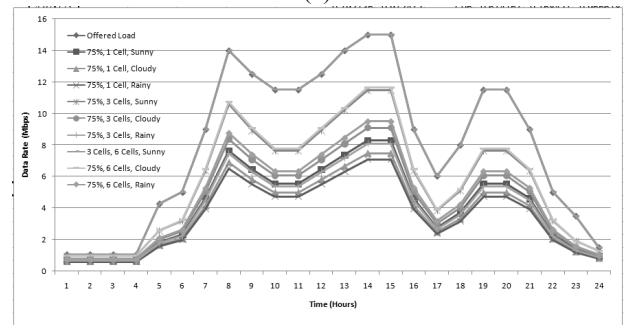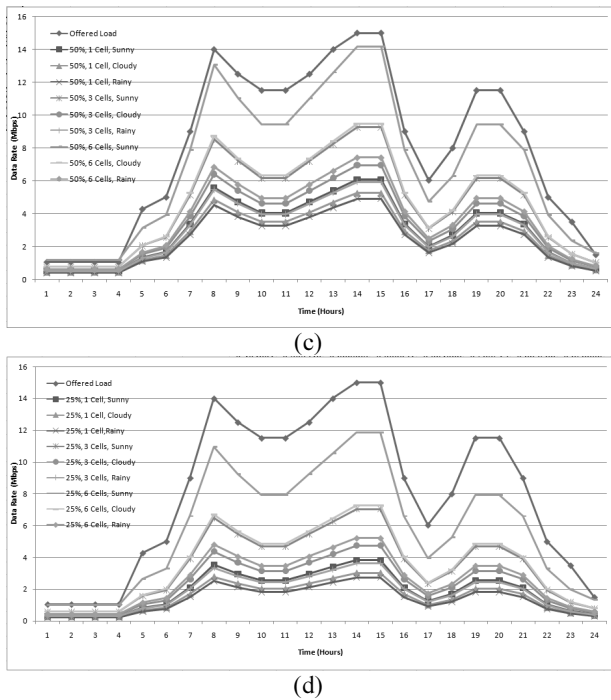
Figure(11) The Daily Behavior of the RSU Working Under CDC Technique

Our next step (in a future separate paper) is to decrease the packets delay produced by the adoption of the CDC technique. This can be achieved if we divide the whole Sleep period (in each second) into several sub-periods which yields packets to be processed in a faster and more efficient way.

10.Conclusions

This paper deals with the design procedure of a solar cell energy harvesting circuit for VANET's Road Side Units(RSU). RSUs are important devices and play an important role in the VANET's infrastructure. The continuous operation of these devices guarantees the success of the VANET's existence goals. On the other hand, the ability to harvest energy from the environment represents an important technology area that promises to eliminate wires and battery maintenance for VANET's applications and permits deploying self powered RSUs. The integration between these technologies and the wise management of the power resources creates a solid foundation to establish a reliable VANET infrastructure.

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