J. Modern Technology & Engineering
Vol.2, No.2, 2017, pp.114-132

# GREEN WIRELESS ACCESS POINT (AP): IMPLEMENTATION METHODOLOGY AND POWER MANAGEMENT

**Qutaiba I. Ali, Jalal K. Jalal**

Mosul University, Mosul City, Iraq

**Abstract.** In this paper, we've applied several steps towards the deployment of a green wireless access point (AP) by investigating the electrical power consumption behavior of the IEEE 802.11a/b/g operating modes to determine how the energy is consumed in a wireless AP. Furthermore, we've dealt with the energy saving strategy for a battery operated wireless AP with an uninterrupted long-term operation using a solar energy harvesting system. The contributions of this work can be expressed by firstly setting up an experimentally–driven approach to measure the electrical current consumption for the proposed wireless (AP) working under different 802.11a/b/g standards then analyzing the electric current consumption results and evaluating the amount of energy consumed by each one of the mentioned standards. The next step involves designing a more energy-efficient wireless (AP) based on the solar energy by utilizing the results obtained from the laboratory experiments of the proposed wireless (AP). The last step was achieved by proposing a new techniques to handle the stored energy, the first technique is the Battery Share Algorithm (BSA) which helps the solar powered AP to fairly distribute the energy stored in the battery cells. The second technique helps to extend the battery discharging time by using a proposed traffic control strategy. Both techniques can maintain the probable operation of a solar powered AP during the periods of solar energy deficit.

***Keywords:*** *green networking, solar energy harvesting, access point, IEEE 802.11 standard, power management.*

***Corresponding Author:*** *Qutaiba Ali, Computer Engineering Department, Mosul University, Mosul City, Iraq, e-mail: qut1974@gmail.com*

***Manuscript received:*** *13 March 2017*

## 1. Introduction

Wireless Access Point (AP) is a device that logically connects the wireless client devices operating in an infrastructure to one another and provides access to a distribution system. With a wireless AP, the wireless LAN can operates in the infrastructure mode. The Access point is simply an electronic card mounted on a motherboard and contains one or more WLAN cards which are also divided into two major sections: the analog Radio Frequency (RF) and the digital processing Medium Access Control (MAC) and connects to the host board through the PC Card or Compact Flash interface [1-4]. The hotspot term refers to the wireless (AP) which often works on Wi-Fi technology and offering free public wireless network access. It is generally a public wireless (AP) where the authentication and verification features are turned off. The 802.11a/b/g dual-band access points with two radios are an example used of hotspot wireless (AP). These access points can support both 2.4 GHz (802.11b/g) and 5 GHz (802.11a) RF bands; they offer backward compatibility (to preserve existing investments) along with a larger number of channels and consequently increased throughput [1-4].

This paper deals with the design procedure of a green IEEE802.11 wireless repeater, although IEEE 802.11 is a very well-known technology and extremely inexpensive, it still requires some experimental design in order to run this technology on solar energy source. Previous works in this field follow different research directions. The first group of studies deal with the power consumption of wireless Access Points, and determine the possible means to reduce the energy requirement of the Access Point .For instance, A. Murabito [11], who studies the impacts of modifying the various configuration parameters and compares the amount of electrical energy consumed by a wireless Access Point in different environments. Also, S. Chiaravalloti, et al, [7] established an APs power consumption database from publicly available product datasheets. This database is useful as a reference for the research community interested in power consumption of WLANs. K. Mabell and G. Chavez [12] focus on monitoring and analyzing the power consumption of wireless access devices using real–test bed and experimental measurements in order to understand the fundamental limits and trade-offs involved. Finally, K. Gomez, et al. [10] use real–world measurements to present a complete analysis of the power consumption and performance of IEEE 802.11n. The second research direction shares the objective of determining a cost-effective and eco-friendly approach for the implementation of a wide area wireless network in isolated rural areas that often lack global telecommunication networks, because of lack of electricity in many areas, and the accessibility problems that make it difficult to propose realistic solutions based on the conventional technologies. F. Reigadas, et al. [15] present the development of an autonomous solar-powered wireless node for low-cost, static mesh networks, where IEEE 802.11 was used for communication among nodes. The network is QoS-aware at the IP level, providing reliable VoIP services, and nodes contain a PBX software so that any two nodes in the network can establish a multihop VoIP communication. The third group of studies investigates the installation and operation of WLAN nodes using an energy sustainable source such as solar power. Node resources assignment consists of provisioning each node with a solar panel and a battery combination that is sufficient to prevent the node outage for the duration of the deployment. Also when some of the wireless nodes are operated using a sustainable solar energy source, nodes upgrades must take into account the cost of updating the node energy resource configurations. This is required so that the new network configuration can properly accommodates the updated energy workloads of the re-provisioned network. G. Badawy; et al. [5] considers the resource assignment problem with the objective of minimizing the total battery cost for a given energy source assignment. Also, S. Karve and S. Kamble [6] use Solar power to drive remote networking components such as a wireless repeater.

## 2. Energy harvesting & storage techniques

Energy harvesting devices can harvest different kinds of energy, including radio frequency, solar, thermal, and vibration. In addition, a single device can harvest energy from multiple ambient energy sources such as Radio frequency

(RF), Acoustic, Thermoelectric [TE], Vibration harvesters and Solar energy harvesting [13-17]. Solar energy harvesting devices use photovoltaic (PV) cells to convert incident light into electricity. As such, they leverage the extensive investments made and progress achieved in increasing the efficiency and reducing the cost of PV for building- and utility-scale power. Relative to other sources, solar devices can achieve high energy densities when used in direct sun, but will not function in areas without light (e.g., highly shaded areas, ducts) [13,14]. Applications to date include contact and motion sensors for building applications, [15] as well as calculators, PDAs, and wristwatches [13]. Table 1 shows the power generation potential of several energy harvesting modalities [16]. While a wide variety of harvesting modalities are now feasible, solar energy harvesting through photo-voltaic conversion provides the highest power density, which makes it the modality of choice to power an embedded system that consumes several mW using a reasonably small harvesting module.

Perhaps the most complex (and crucial) design decision involves the energy storage mechanism. The two choices available for energy storage are batteries and electrochemical double layer capacitors, also known as ultracapacitors. The batteries used in this study have a nominal voltage (12 V) and they come in a variety of ranges (sizes). Batteries size are rated by their amp-hours (Ah) storage capacity. The batteries in solar harvesting need a regulator (or more formally, the solar power charge regulator) ensures that the battery is working in appropriate conditions and it prevents battery overcharging or over discharging If the equipment that you want to power uses a different DC voltage than the one supplied by the battery, we will need to use a DC/DC converter the efficiency of the charging and converting equipment [15]. The most popular solar charger controllers for small systems use pulse width modulation (PWM) that regulate the charge current to the battery. This switching technology results in minimum power dissipation in the controller and generally supports fast charging of the battery through a three step process (constant current, constant voltage, float) [16].

**Table 1.** Power densities of harvesting technologies

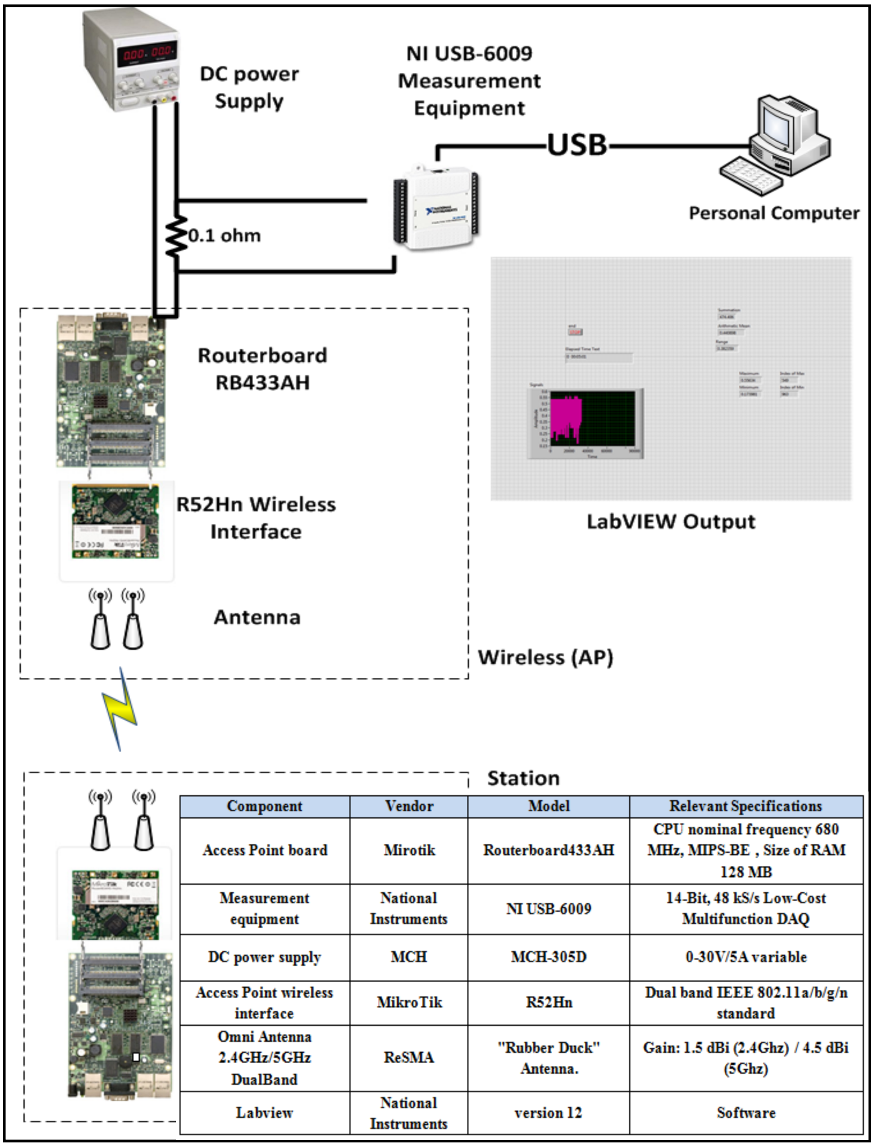
| Harvesting Technology | Power Density |
|---|---|
| Solar Cells | 15 mW/Cm$^2$ |
| Piezoelectric | 330 μW/ Cm$^3$ |
| Vibration | 116 μW/ Cm$^3$ |
| Thermoelectric | 40 μW/ Cm$^3$ |
| Acoustic noise | 960 nW/ Cm$^3$ |

## 3. Design methodology of a solar-powered wireless access point

This section proposes the deployment strategy of a green wireless (AP) using solar energy harvesting and investigates the possibility of different implementations according to the standards and its sub rates. Here, the cost means the number of panels, capacity of the batteries and the solar panel size in watts.

The experimental results show that there are changes in the behaviour of energy consumption for different standards, sub rates and transmitting power. From this it can be deduced that the choice of a specific standard will affect on the size and cost of the system.

The design of a solar-powered wireless requires the understanding of the behavior of an electrical current drained by the Access Point in different circumstances in order to determine the optimum values of the design [18]. In this paper, we suggest the experimental lab setup shown in Figure 1. In these tests we changed three variables: Wireless technology 802.11 a/b/g, Modulation and Coding (data rate) and the transmitter power level . In each run we changed the variables and calculate the throughput and the drained current. Optimum values derived from the results were placed in Table 2. The optimal values provide maximum throughput with minimum drained current.




| Component | Vendor | Model | Relevant Specifications |
|---|---|---|---|
| Access Point board | Mirotik | Routerboard433AH | CPU nominal frequency 680 MHz, MIPS-BE , Size of RAM 128 MB |
| Measurement equipment | National Instruments | NI USB-6009 | 14-Bit, 48 kS/s Low-Cost Multifunction DAQ |
| DC power supply | MCH | MCH-305D | 0-30V/5A variable |
| Access Point wireless interface | MikroTik | R52Hn | Dual band IEEE 802.11a/b/g/n standard |
| Omni Antenna 2.4GHz/5GHz DualBand | ReSMA | "Rubber Duck" Antenna. | Gain: 1.5 dBi (2.4Ghz) / 4.5 dBi (5Ghz) |
| Labview | National Instruments | version 12 | Software |

**Figure1**. Experimental setup

**Table 2.** Optimum values which provide maximum throughput with minimum drained current

| | Data Rate (Mbps) | $TX_p$ | $I_{mean}$ TX (A) | $I_{mean}$ RX(A) | $T_p$ Mbps |
|---|---|---|---|---|---|
| 802.11a | 6 | 1 | 0.43129 | 0.242499 | 5.25 |
| | 12 | 1 | 0.416676 | 0.242809 | 9.85 |
| | 24 | 1 | 0.405716 | 0.25023 | 17.25 |
| | 54 | 1 | 0.371308 | 0.259092 | 29.85 |
| 802.11b | 1 | 6 | 0.277707 | 0.226118 | 0.906 |
| | 5.5 | 3 | 0.270413 | 0.231624 | 4.4 5 |
| | 11 | 1 | 0.263833 | 0.227778 | 7.85 |
| 802.11g | 6 | 1 | 0.281181 | 0.233523 | 5.95 |
| | 12 | 1 | 0.27058 | 0.232356 | 9.45 |
| | 24 | 3 | 0.272175 | 0.235635 | 16.2 |
| | 54 | 1 | 0.261897 | 0.238224 | 21.35 |

This case study describes a methodology of designing an energy efficient solar-powered backhaul wireless hotspot based on IEEE 802.11a/b/g. Figure 2 shows the proposed Wireless backhaul by using Mikrotik Routerboard 433AH [18] integrated with two wireless interfaces: one of them is set up as an access point which provides networking service to the clients and the second radio is set up in a dedicated bridge mode. The bridge is linked directly to the network base station or gateway. This section presents the methodology used to determine the best predicted value for the battery and the solar panel specifications depending on the results of the laboratory experiments.

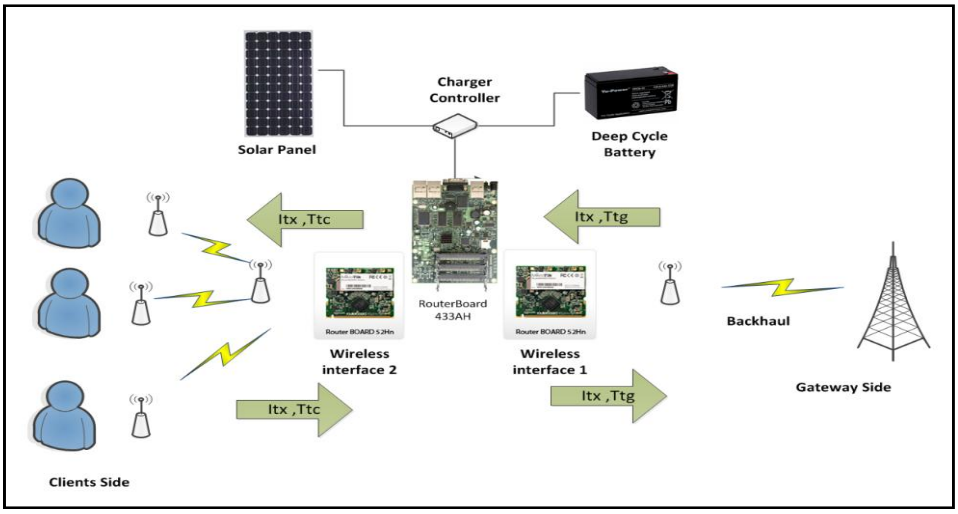



**Figure 2.** The proposed solar-powered wireless backhaul

This methodology needs prerequisite data such as: PSH (Peak Sun Hours) of the deployment area and the historical real-world traffic of the wireless backhaul. The method consists of the following steps:

1. The first step is to determine the optimum values of (Itx, Irx) of each standard and the related sub rate by using the experimental lab as shown in earlier. Where Itx is the optimum average drained current (transmitting), Irx is the optimum average drained current (receiving).
2. The next step is to calculate the TX and the RX time in the WLAN interface by using real world traffic patterns. This study used the (upload, download) total traffic is based on the assumption that the traffic ratio of (upload, download) is equal to the time ratio of (TX, RX).

$$T_{tc}/R_{tc} = \text{upload traffic / download traffic} \quad (1)$$

$$T_{tg}/R_{tg} = \text{download traffic / upload traffic} \quad (2)$$

where $T_{tc}$ is the TX time in the client side, $R_{tc}$ is the RX time in client side $T_{tg}$ is the TX time in gateway side, $R_{tg}$ is the Rx time in gateway side.

3. The next step is to calculate the size of the batteries needed to energize the wireless AP during the night hours.

$$B_{total} = ( B_{client} + B_{gateway} ) – (I_{board} \times T) \quad (3)$$

where $B_{client}$ is the Battery size required to run the AP with one wireless interface (client side), $B_{gateway}$ is the battery size required to run the AP with one wireless interface (gateway side); T is the total running time in the longest night, $I_{board}$ is the current drained by the APs' motherboard and it was found to be (0.18706 A) for this specific AP.

$$Bclient = (T_{tc} \times Irx) + (R_{tc} \times Itx) \quad (4)$$

where Itx is the optimum average drained current (transmitting) for the client side, Irx is the optimum average drained current (receiving) for the client side.

$$Bgateway = (R_{tg} \times Itx) + (T_{tc} \times Irx) \quad (5)$$

where Itx is the optimum average drained current (transmitting) for the gateway side, Irx, is the optimum average drained current (receiving) for the gateway side.

4. In order to extend the battery life, the battery size will be extended by 20%.

$$B_{size} = 0.2\, B_{total} + B_{total} \quad (6)$$

where Bsize, is the battery size required to run the wireless (AP) with two WLAN interfaces.

5. This step uses the average (PSH) to calculate the charging current for the battery cells. PSH are the number of hours required for a day's total solar irradiation to accumulate at peak sun condition. The total irradiation for a day may be expressed in units of peak sun hours by dividing by 1000 W/m$^2$ (peak sun irradiance).

$$I_c = B_{size} / PSH \quad (7)$$

where $I_c$ is the current provided to charge the battery cells.

6. The traditional operation of a wireless AP involves either sending or receiving data packets to/from each interface at any time. The maximum drained current is equal to summation of the maximum (Itx) in the client or gateway side plus the maximum current drained (Irx) in the reversed direction.

$$I_{total} = Itx + Irx \quad (8)$$

where $I_{total}$ is the current required to run the wireless AP.

$$I_{panel} = I_{total} + I_c \quad (9)$$

where $I_{panel}$ is the electric current provided by the solar panel.

In order to validate the proposed design methodology, the following example demonstrates a case study of implementing a cost-effective solar-powered wireless backhaul AP that provides wireless network access in isolated areas in (Mosul city /Iraq). The solar-powered wireless backhaul AP is constructed using the components in Figure 2. The solar panel is used to supply the wireless (AP) equipment during the day period, and at the same time the energy is accumulated in the battery cells in order to supply the system during the hours of darkness. The wireless AP which is used in this case has a dual band WLAN NICs and support 802.11a/b/g standard.

In this case study, the following design assumptions were considered:

- The longest night in the design area is 14 hours at (Dec 21) (i.e. T total =14 hour).
- The graph in Figure 3 shows that the northern regions (Alshamal denotes Mosul) receive a 4 average peak sun hours, so that (PSH =4).
- The graph in Figure 4 shows that the maximum throughput is equal to 6.685 Mbps.
- The graph in Figure 4 shows that the traffic ratio reported from the wireless AP is equal to (0.17).
- The idle state (there is no (TX or RX) traffic) can be ignored in the calculation as wireless (AP) consumes much less energy as compared with active states.
- The $I_{board}$ is equal to 0.18706 A.

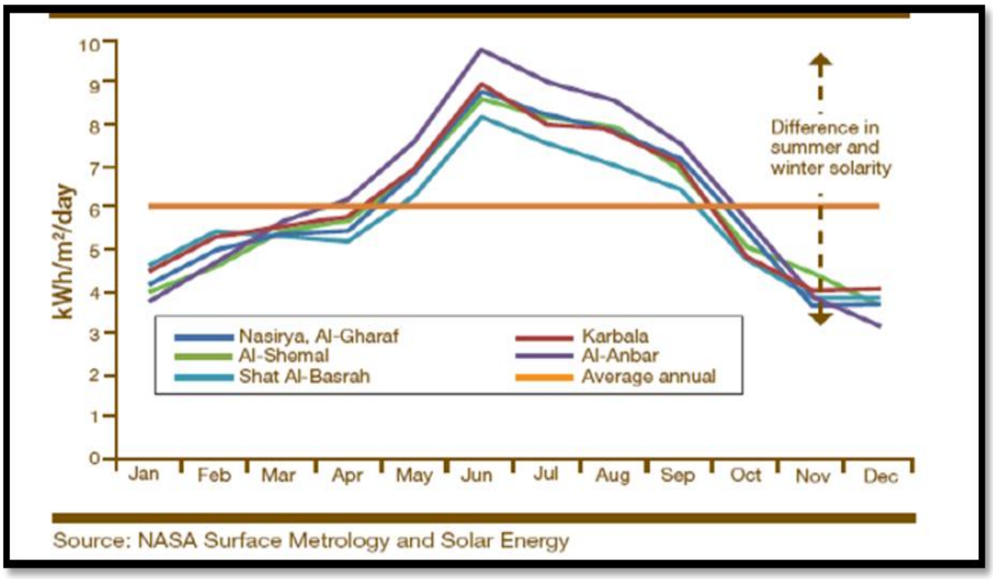



**Figure 3.** The average PSH during all months in the year in the northern regions where Mosul city is located

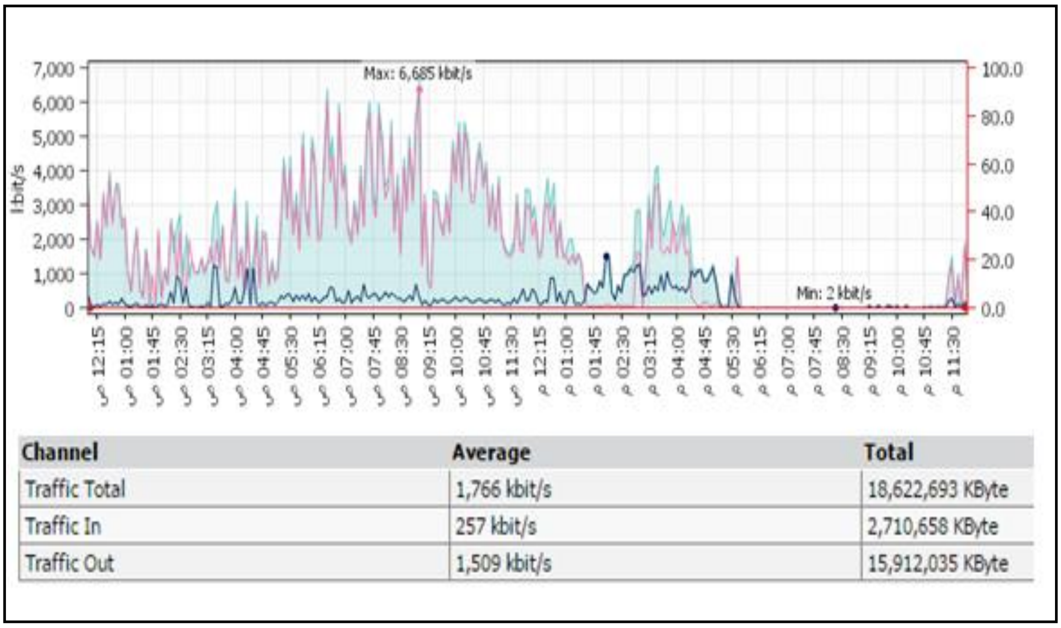



**Figure 4.**The snapshot traffic for hotspot wireless AP shows maximum throughput and traffic ratio

In order calculate the ratio of transmitting to receiving time, we used eq.1 while feeding it with the traffic reported in Figure 4 where:
$T_{tc}$ = 11.615 hour, $R_{tc}$ = 2.385 hour, $T_{tg}$ = 2.385 hour, $R_{tg}$ =11.615 hour. The values in Table 3 list a summary of the calculated values of ($I_{total}$, $I_c$, $I_{panel}$ and $B_{size}$) for the backhaul wireless repeater using 802.11a/b/g optimum values (as listed earlier in Table 2).

**Table 3.** The possible values of system calculation

| 802.11 Clients | I mean TX (A) | I mean RX(A) | 802.11 Backhaul | Imean TX (A) | Imean RX(A) | Itotal(A) (*1) | Ic (A) (*2) | Ipanel(A) (*3) | Bsize(AH) (*4) | Tp Mbps Backhaul | Tp Mbps Client |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | 0.277707 | 0.226118 | A6 | 0.43129 | 0.242499 | 0.657408 | 1.497381 | 2.154789 | 5.989525 | 5.25 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | A6 | 0.43129 | 0.242499 | 0.662914 | 1.475905 | 2.138819 | 5.903619 | 5.25 | 4.4 5 |
| B1 | 0.277707 | 0.226118 | A12 | 0.416676 | 0.242809 | 0.642794 | 1.488005 | 2.130799 | 5.95202 | 9.85 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | A12 | 0.416676 | 0.242809 | 0.6483 | 1.466529 | 2.114829 | 5.866115 | 9.85 | 4.4 5 |
| B11 | 0.263833 | 0.227778 | A12 | 0.416676 | 0.242809 | 0.644454 | 1.440849 | 2.085303 | 5.763396 | 9.85 | 7.85 |
| B1 | 0.277707 | 0.226118 | A24 | 0.405716 | 0.25023 | 0.631834 | 1.506022 | 2.137856 | 6.024087 | 17.25 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | A24 | 0.405716 | 0.25023 | 0.63734 | 1.484545 | 2.121885 | 5.938181 | 17.25 | 4.4 5 |
| B11 | 0.263833 | 0.227778 | A24 | 0.405716 | 0.25023 | 0.633494 | 1.458865 | 2.092359 | 5.835462 | 17.25 | 7.85 |
| B1 | 0.263833 | 0.227778 | A54 | 0.371308 | 0.259092 | 0.599086 | 1.465126 | 2.064212 | 5.860505 | 29.85 | 0.906 |
| B5.5 | 0.277707 | 0.226118 | A54 | 0.371308 | 0.259092 | 0.597426 | 1.512282 | 2.109708 | 6.04913 | 29.85 | 4.4 5 |
| B11 | 0.270413 | 0.231624 | A54 | 0.371308 | 0.259092 | 0.602932 | 1.490806 | 2.093738 | 5.963224 | 29.85 | 7.85 |
| G6 | 0.281181 | 0.233523 | A12 | 0.416676 | 0.242809 | 0.650199 | 1.505409 | 2.155608 | 6.021634 | 9.85 | 5.95 |
| G12 | 0.27058 | 0.232356 | A12 | 0.416676 | 0.242809 | 0.649032 | 1.467634 | 2.116666 | 5.870537 | 9.85 | 9.45 |

| 802.11 Clients | I mean TX (A) | I mean RX(A) | 802.11 Backhaul | Imean TX (A) | Imean RX(A) | Itotal(A) (*1) | Ic (A) (*2) | Ipanel(A) (*3) | Bsize(AH) (*4) | Tp Mbps Backhaul | Tp Mbps Client |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G24 | 0.272175 | 0.235635 | A12 | 0.416676 | 0.242809 | 0.652311 | 1.475538 | 2.127849 | 5.902153 | 17.25 | 16.2 |
| G6 | 0.281181 | 0.233523 | A24 | 0.405716 | 0.25023 | 0.639239 | 1.523425 | 2.162664 | 6.093701 | 17.25 | 5.95 |
| G12 | 0.27058 | 0.232356 | A24 | 0.405716 | 0.25023 | 0.638072 | 1.485651 | 2.123723 | 5.942604 | 29.85 | 9.45 |
| G24 | 0.272175 | 0.235635 | A24 | 0.405716 | 0.25023 | 0.641351 | 1.493555 | 2.134906 | 5.974219 | 29.85 | 16.2 |
| G54 | 0.261897 | 0.238224 | A24 | 0.405716 | 0.25023 | 0.64394 | 1.459594 | 2.103534 | 5.838374 | 29.85 | 21.35 |
| A6 | 0.43129 | 0.242499 | A6 | 0.43129 | 0.242499 | 0.673789 | 2.044262 | 2.718051 | 8.177047 | 5.25 | 5.25 |
| A6 | 0.43129 | 0.242499 | A12 | 0.416676 | 0.242809 | 0.674099 | 2.034886 | 2.708985 | 8.139543 | 9.85 | 5.25 |
| A12 | 0.416676 | 0.242809 | A12 | 0.416676 | 0.242809 | 0.659485 | 1.984185 | 2.64367 | 7.93674 | 9.85 | 9.85 |
| A6 | 0.43129 | 0.242499 | A24 | 0.405716 | 0.25023 | 0.68152 | 2.052902 | 2.734422 | 8.211609 | 17.25 | 5.25 |
| A12 | 0.416676 | 0.242809 | A24 | 0.405716 | 0.25023 | 0.666906 | 2.002202 | 2.669108 | 8.008806 | 17.25 | 9.85 |
| A24 | 0.405716 | 0.25023 | A24 | 0.405716 | 0.25023 | 0.655946 | 1.969321 | 2.625267 | 7.877285 | 17.25 | 17.25 |
| A6 | 0.43129 | 0.242499 | A54 | 0.371308 | 0.259092 | 0.690382 | 2.059163 | 2.749545 | 8.236652 | 29.85 | 5.25 |
| A12 | 0.416676 | 0.242809 | A54 | 0.371308 | 0.259092 | 0.6575768 | 2.008462 | 2.68423 | 8.033849 | 29.85 | 9.85 |
| A24 | 0.405716 | 0.25023 | A54 | 0.371308 | 0.259092 | 0.664808 | 1.975582 | 2.64039 | 7.902328 | 29.85 | 17.25 |
| A54 | 0.371308 | 0.259092 | A54 | 0.371308 | 0.259092 | 0.6304 | 1.862028 | 2.492428 | 7.448112 | 29.85 | 29.85 |
| B1 | 0.277707 | 0.226118 | G6 | 0.281181 | 0.233523 | 0.507299 | 1.358701 | 1.866 | 5.434805 | 5.95 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | G6 | 0.281181 | 0.233523 | 0.512805 | 1.337225 | 1.85003 | 5.3489 | 5.95 | 4.4 5 |
| B1 | 0.277707 | 0.226118 | G12 | 0.27058 | 0.232356 | 0.503825 | 1.34705 | 1.850875 | 5.3882 | 9.45 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | G12 | 0.27058 | 0.232356 | 0.502204 | 1.325574 | 1.827778 | 5.302294 | 9.45 | 4.4 5 |
| B11 | 0.263833 | 0.227778 | G12 | 0.27058 | 0.232356 | 0.498358 | 1.299894 | 1.798252 | 5.199575 | 9.45 | 7.85 |
| B1 | 0.277707 | 0.226118 | G24 | 0.272175 | 0.235635 | 0.503825 | 1.359617 | 1.863442 | 5.438467 | 16.2 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | G24 | 0.272175 | 0.235635 | 0.503799 | 1.33814 | 1.841939 | 5.352562 | 16.2 | 4.4 5 |
| B11 | 0.263833 | 0.227778 | G24 | 0.272175 | 0.235635 | 0.499953 | 1.312461 | 1.812414 | 5.249842 | 16.2 | 7.85 |
| B1 | 0.277707 | 0.226118 | G54 | 0.261897 | 0.238224 | 0.503825 | 1.361284 | 1.865109 | 5.445137 | 21.35 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | G54 | 0.261897 | 0.238224 | 0.508637 | 1.339808 | 1.848445 | 5.359232 | 21.35 | 4.4 5 |
| B11 | 0.263833 | 0.227778 | G54 | 0.261897 | 0.238224 | 0.502057 | 1.314128 | 1.816185 | 5.256512 | 21.35 | 7.85 |
| G6 | 0.281181 | 0.233523 | G6 | 0.281181 | 0.233523 | 0.514704 | 1.376105 | 1.890809 | 5.504419 | 5.95 | 5.95 |
| G24 | 0.272175 | 0.235635 | G6 | 0.281181 | 0.233523 | 0.516816 | 1.346235 | 1.863051 | 5.384938 | 16.2 | 16.2 |
| G54 | 0.261897 | 0.238224 | G6 | 0.281181 | 0.233523 | 0.519405 | 1.312273 | 1.831678 | 5.249093 | 21.35 | 5.95 |
| G6 | 0.281181 | 0.233523 | G12 | 0.27058 | 0.232356 | 0.513537 | 1.364453 | 1.87799 | 5.457813 | 7.85 | 5.95 |
| G12 | 0.27058 | 0.232356 | G12 | 0.27058 | 0.232356 | 0.502936 | 1.326679 | 1.829615 | 5.306717 | 9.45 | 9.45 |
| G24 | 0.272175 | 0.235635 | G12 | 0.27058 | 0.232356 | 0.504735 | 1.334583 | 1.839318 | 5.338332 | 16.2 | 9.45 |
| G6 | 0.281181 | 0.233523 | G24 | 0.272175 | 0.235635 | 0.516816 | 1.37702 | 1.891724 | 5.508081 | 16.2 | 5.95 |
| G12 | 0.27058 | 0.232356 | G24 | 0.272175 | 0.235635 | 0.504531 | 1.339246 | 1.843777 | 5.356984 | 16.2 | 9.45 |
| G24 | 0.272175 | 0.235635 | G24 | 0.272175 | 0.235635 | 0.50781 | 1.34715 | 1.85496 | 5.3886 | 16.2 | 16.2 |
| G6 | 0.281181 | 0.233523 | G54 | 0.261897 | 0.238224 | 0.519405 | 1.378688 | 1.898093 | 5.514751 | 21.35 | 5.95 |
| G12 | 0.27058 | 0.232356 | G54 | 0.261897 | 0.238224 | 0.508804 | 1.340914 | 1.84971 | 5.363654 | 21.35 | 9.45 |
| G24 | 0.272175 | 0.235635 | G54 | 0.261897 | 0.238224 | 0.510399 | 1.348817 | 1.856627 | 5.39527 | 21.35 | 16.2 |
| G54 | 0.261897 | 0.238224 | G54 | 0.261897 | 0.238224 | 0.500121 | 1.314856 | 1.814977 | 5.259425 | 21.35 | 21.35 |
| G6 | 0.281181 | 0.233523 | B11 | 0.263833 | 0.227778 | 0.508959 | 1.343674 | 1.852633 | 5.374695 | 7.85 | 5.95 |
| A6 | 0.281181 | 0.233523 | B11 | 0.263833 | 0.227778 | 0.508959 | 1.343674 | 1.852633 | 5.374695 | 7.85 | 5.2 |
| B1 | 0.277707 | 0.226118 | B5.5 | 0.270413 | 0.231624 | 0.509331 | 1.34438 | 1.853711 | 5.377519 | 4.4 5 | 0.906 |
| B5.5 | 0.270413 | 0.231624 | B5.5 | 0.270413 | 0.231624 | 0.502037 | 1.322903 | 1.82494 | 5.291614 | 4.4 5 | 4.4 5 |
| B1 | 0.277707 | 0.226118 | B1 | 0.277707 | 0.226118 | 0.503825 | 1.330413 | 1.834238 | 5.321652 | 0.906 | 0.906 |

| 802.11 Clients | I mean TX (A) | I mean RX(A) | 802.11 Backhaul | Imean TX (A) | Imean RX(A) | Itotal(A) (*1) | Ic (A) (*2) | Ipanel(A) (*3) | Bsize(AH) (*4) | Tp Mbps Backhaul | Tp Mbps Client |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B5.5 | 0.270413 | 0.231624 | B11 | 0.263833 | 0.227778 | 0.498191 | 1.304794 | 1.802985 | 5.219176 | 7.85 | 4.4 5 |

*1 using Eq. (8 ) , *2 using Eq. (.7) , *3 using Eq. (9) , *4 using Eq. (6 ) , A =802.11a , B = 802.11b , G = 802.11g

It is worth to mention that some possible values were omitted because the total throughput ($T_p$) in the client side is greater than $T_p$ value in the backhaul gateway which could mean loss of data, due to the congestion.

From the table above, we can deduce that choosing the best energy efficient values from Table 3 depends on both the network deployment and the application requirements. For example: in this case study, the wireless (AP) requires a minimum throughput of 6.624 Mbps (see Figure4). Table 4 describes the comparison of choosing available options in order to understand the reduction in the system size in terms of the cost and performance.

Finally, it is important to mention that the batteries and the solar panels are available in different sizes and features and restricted by certain commercial and technical issues in addition to the cost. In this study, we proposed Shell ST-20 solar panel with technical specification listed in appendix (A) [19]. Table 4 shows the number of parallel (20 watt) panels and the battery size required for this case study.

**Table 4.** The recommended number of solar panel, charger controller and battery for solar-powered wireless backhaul AP

| | Client Standard | Backhaul Standard | Client Data Rate | Backhaul Data Rate | Ipanel | Number of panel | Available battery AH | Client Tp | backhaul Tp | Charger Controller V/A |
|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 802.11b | 802.11b | B11 | G12 | 1.798252 | 2 | 6 | 0.906 | 0.906 | 12/2.5 |
| **Optimum** | 802.11g | 802.11g | G54 | G54 | 1.814977 | 2 | 6 | 21.35 | 21.35 | 12/2.5 |
| **Maximum** | 802.11a | 802.11a | A6 | A54 | 2.749545 | 3 | 9 | 5.25 | 29.85 | 12/3.5 |

*The proposed solar panel can provide 1.2A short circuit current (Isc) in normal condition(appendix A) , so we can calculate the number of the required panels by dividing the (Ipanel) for each case by 1.2A and the number of panels are the integer values in the practical usage.

The results in Table 4 show that, if the solar powered wireless backhaul using IEEE 802.11g with 54 data rate is the best option in this case study; both the number of panels and the battery size is reduced by about 33% in companion with the maximum case. This reduction will be very effective if we take into account the cost and the size of the system in addition to the number of wireless APs required for deployment.

## 4. The proposed power management techniques for solar powered wireless (AP)

The solar wireless (AP) which was designed in section (4) used the average PSH in the design calculations (i.e. in the area of Mosul city-Iraq, the average daily PSH hours was equal (4)). In some weather cases (e.g. dark cloud, snow and etc), PSH is reduced to approximately 1.8, this leads the system to harvest a small percentage of the solar energy with a limited energy stored in the battery cells. In such cases, the users (stations) may unfairly utilize the battery capacity (i.e., the stored energy ), leading the system to shutdown during the night hours (no incident light). In order to solve such problems, we proposed two power management techniques as shown in Figure 5, both techniques are mainly supported by the solar powered (AP) to extend or preserve the battery energy at the night periods.

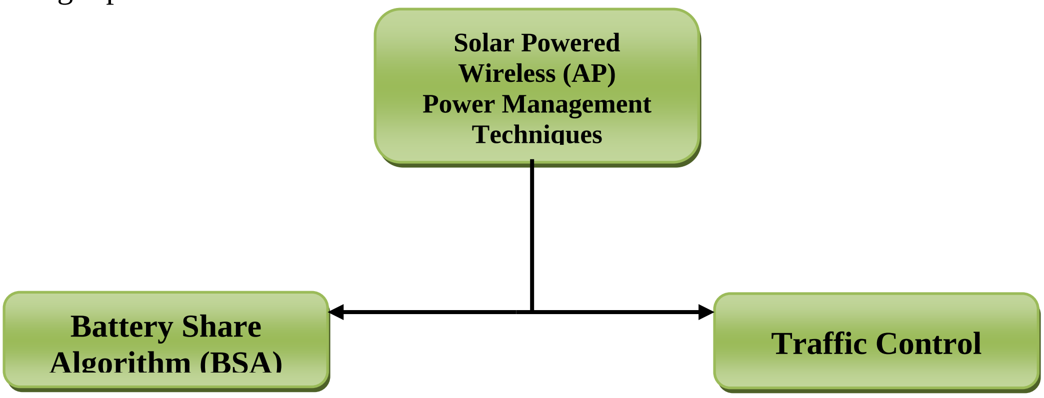



**Figure5.** The proposed power management techniques

### *4.1. The proposed battery share algorithm (BSA)*

The previous section presented the calculation methodology of the solar powered (AP) based on lab measurements. In this section, we proposed a new power management procedure called the Battery share Algorithm (BSA), this algorithm appoints a time quota for each client (station) at night period and shares the battery energy with an equitable distribution which prevents one client from discharging all the battery energy in the duration of the night. The proposed algorithm policy imposes the presence of a wireless LAN controller (WLC) or administrator as shown in Figure 6. The WLC allows a central management of the wireless network by using the wireless management protocols (e.g. Control And Provisioning of Wireless Access Point (CAPWAP) [RFC 5415]). The WLC controller has the ability to collect the users statistics, access control and client authentication.

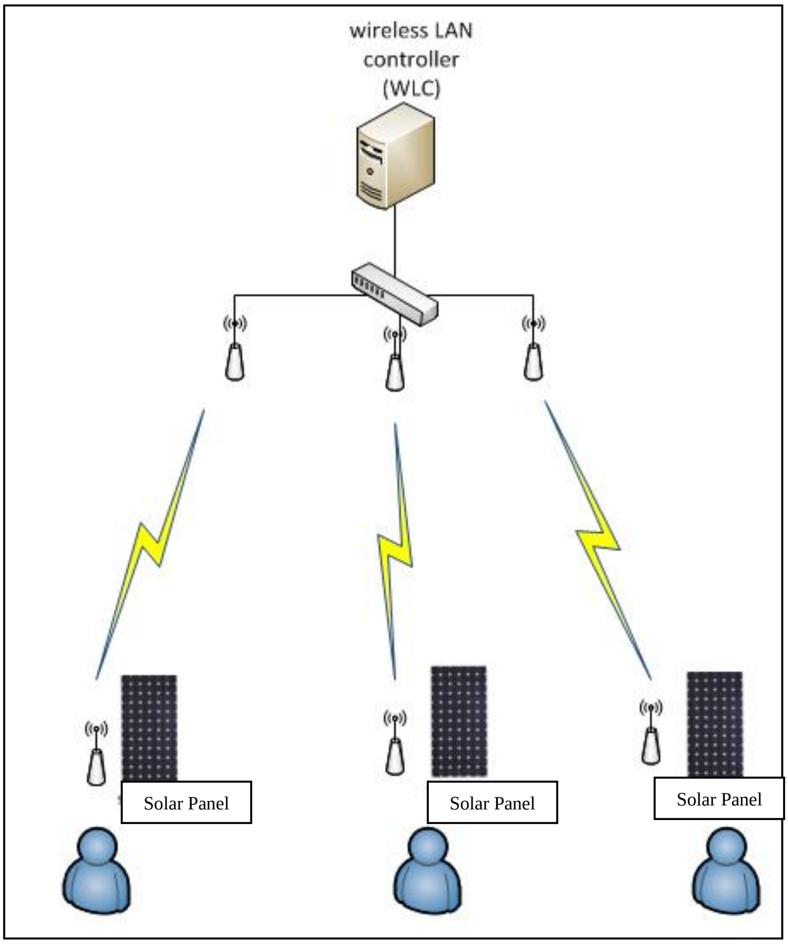



**Figure 6.** The proposed topology for power-saving policies for Wi-Fi hotspots using battery slice based on weather condition

The flow chart in Figure 7 describes the steps of the (BSA) algorithm. Using the meteorological weather data, the network administrator can determine the energy capacity per user relying on this information as following:

**Step 1**. The WLC controller initializes setting.

**Step 2**.The WLC receives the daily weather forecast from the central server or from the network administrator; the WLC maps the weather forecast into an equivalent PSH value.

**Step 3.** The WLC broadcasts the expected (PSH) values to the solar powered wireless (APs) as shown in Figure 6.

**Step 4**. Each AP receives the (PSH) value from the WLC and uses it to calculate the Expected Energy (EE), the AP uses the charging current (Ic) which is provided by the solar panel to calculate the (EE) as following:

$$EE = Ic \times PSH \tag{10}$$

where (EE) is the value of expected energy charge in one day, Ic is the electrical current provided by a solar panel to charge the battery cells.

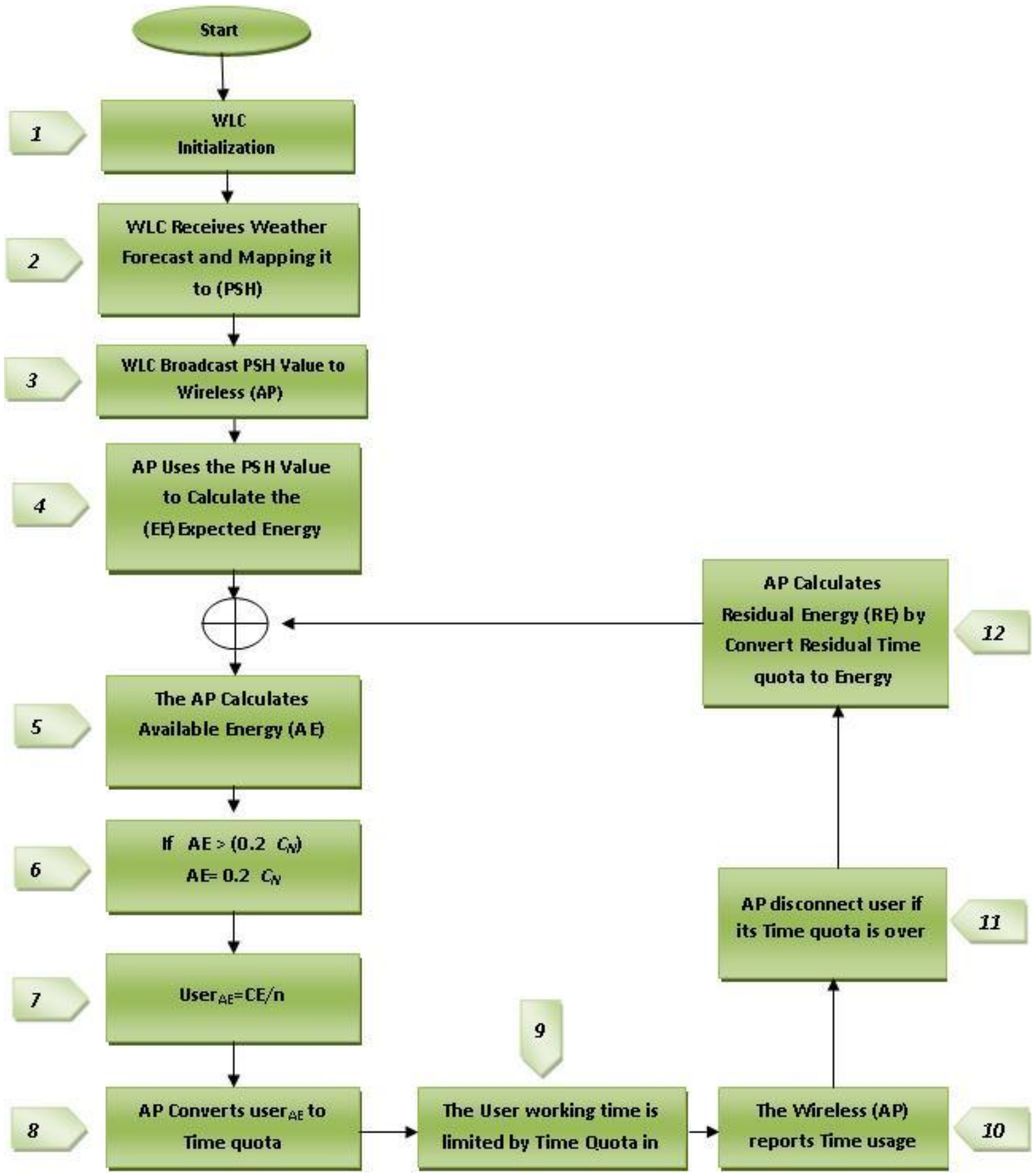



**Figure 7.** Battery share algorithm (BSA) implementation

**Step 5.** The AP calculates the predicted Available Energy (AE) by adding the (EE) with the Residual Energy (RE) from the previous day as following:

$$AE = EE + RE \qquad (11)$$

**Step 6**. In this step, the AP compares the (AE) with the maximum battery size in a solar energy system ($B_{size}$), the total (AE) can be equal to or less than the 20% of the Nominal Capacity ($C_N$ ) of the recommended battery.

**Step 7.** In this step the AP divides the total available energy (AE) by the number of the registered users (n) with it. The AP fairly shares the battery energy, so that each user (station) will have its own portion of battery energy as following:

$$User_{AE} = (AE/n) \qquad (12)$$

**Step 8.** Now, the AP needs to calculate the time quota (per user) by converting the user shared energy into an equivalent time quota (Tq) using the following equations:

$$Tq = User_{AE} \ / (Itx + Irx - I_{board}) \quad (13)$$

Where Tq is the expected time needed by a user station to work at night.

**Step 9.** The AP limits the user (station) time usage by the value of (Tq); the wireless (AP) will disconnect the user's (station) during the night period when the station's time quota is over.

**Step 10.** During the night, the wireless (AP) will report the time usage of the users and calculates the residual time at the end of the night period.

**Step 11.** In this step the AP calculates the Residual Energy (RE) by converting the residual time into equivalent battery energy using the following equation:

$$RE = Tr \times (Itx + Irx - I_{board}) \quad (14)$$

where Tr is the residual time from the previous day (in hours).

Referring to the case study in section (3), the final results of the solar-powered wireless backhaul are summarized in Table 5. The maximum battery size ($B_{size}$) is equal 4.8 Ah (20% from nominal battery size) and the charging current provided by the solar panel at one PSH is equal to (1.314856 A). As shown in Table 5, during the period of bad weather (e.g. Black clouds, snow, sand, etc.), the average peak sun hour (PSH) is reduced approximately to (1.8). Under the poor weather conditions, the battery will not reach the fully charged status and the users may compete unfairly on the use of the' stored energy at the night period which may cause the system to be halted.

**Table 5.** The results and calculations of the case study: solar-powered wireless backhaul

| Optimum Option | Client Standard | Backhaul Standard | Irx(A) | Itx(A) | $I_{board}$ (A) | $I_c$ (A) | Available battery (Ah) | $B_{size}$ (Ah) |
|---|---|---|---|---|---|---|---|---|
| | 802.11g (54) | 802.11g (54) | 0.238224 | 0.261897 | 0.18706 | 1.314856 | 6 | 4.8 |

Table 5 lists the parameters that have been used to conduct the proposed BSA algorithm. The implementation results of the BSA in the case study are included in Table 6 in which different conditions are assumed with constrained number of users (n) while the RE from the previous day is equal to (0% , 20%). However, the worst case is the day of anatomy where (PSH) is equal zero (e.g. the panel is completely covered by the snow), in this scenario, the BSA shares the residual energy only. Table 6 lists the key model parameters including those for a 10 user scenario in which each user connects for up to (45 min ) in bad weather conditions and (70 min) in cloudy weather when RE is equal to (0) (the user can work for (92 min) at sunny days which represents the best case). In the 5 users' scenario, each user can work for (90 min.) for network operation in bad weather condition, a (184 min) in a cloudy weather when RE is equal (0).

**Table 6.** Example of (BSA) implementations

| Weather Condition | Peak Sun Hour PSH [62] | Expected Energy EE (*1) | Residual Energy RE | Available Energy AE (*2) | n | $User_{AE}$ (*3) | Time Quota Tq (hour) (*4) |
|---|---|---|---|---|---|---|---|
| Black clouds, snow, sand | 1.8 | 2.3667 | 0 | 2.3667 | 10 | 0.23667 | 0.7559 |
| Cloudy | 3 | 3.9445 | 0 | 3.9445 | 10 | 0.39445 | 1.2599 |
| Cloudy with less sun | 3.5 | 4.6019 | 0 | 4.6019 | 10 | 0.46019 | 1.1699 |
| Day of anatomy | 0 | 0 | (0.96) 20% | 0.96 | 10 | 0.096 | 0.3066 |
| Black clouds, snow, sand | 1.8 | 2.3667 | (0.96) 20% | 3.3267 | 10 | 0.33267 | 1.06263 |
| Cloudy | 3 | 3.9445 | (0.96) 20% | 4.9045 | 10 | 0.48 | 1.5332 |
| Cloudy with less sun | 3.5 | 4.6019 | (0.96) 20% | 5.5619 | 10 | 0.48 | 1.5332 |
| Black clouds, snow, sand | 1.8 | 2.3667 | 0 | 2.3667 | 5 | 0.47334 | 1.5119 |
| Cloudy | 3 | 3.9445 | 0 | 3.9445 | 5 | 0.7889 | 2.5199 |
| Cloudy with less sun | 3.5 | 4.6019 | 0 | 4.6019 | 5 | 0.92038 | 2.9399 |
| Day of anatomy | 0 | 0 | (0.96) 20% | 0.96 | 5 | 0.192 | 0.6132 |
| Black clouds, snow, sand | 1.8 | 2.3667 | (0.96) 20% | 3.3267 | 5 | 0.6653 | 2.1252 |
| Cloudy | 3 | 3.9445 | (0.96) 20% | 4.9045 | 5 | 0.96 | 3.066 |
| Cloudy with less sun | 3.5 | 4.6019 | (0.96) 20% | 5.5709 | 5 | 0.96 | 3.066 |

(*1) using Eq.(10); (*2) using Eq. (11); (*3) using Eq. (12);, (*4) using Eq. (13)

### *4.2. Extending battery working time*

In this paper, we proposed a second approach to prolong the battery discharging time for an additional period during the night by controlling the traffic rate passes through the wireless AP using traffic control strategies; this method is verified through the laboratory experiments by changing the traffic speed (data rate) while running the wireless (AP). The battery discharging time represents the total time of supplying the energy from the battery to the wireless (AP) until the battery reaches 20% of its nominal capacity, so that $D_{max}$ is equal 20%. Referring to the case study in Table 3 the IEEE 802.11g with 54 Mbps data rate is used in the solar powered AP on both client (users) and gateway side, and the maximum achieved throughput (Tp) in this data rate is 21.35 Mbps. The following experiment is built to test the effect of changing the traffic rate on battery capacity in this case study, we used an experiments driven approach to measure the battery discharging time of an IEEE 802.11(54) AP with different traffic rates as following:

1- The experiment scenario used Lead-Acid battery with nominal capacity $C_N$ is equal 4.5 AH energy capacity and $V_N$ equal to 12 volt to supply the energy of the tested wireless(AP). The battery was externally charged to 100% of its capacity before being used.
2- We used the “Bandwidth Test Tool” to synthesizing the network traffic between two wirelesses (APs) while the average throughput was fixed to (5.25, 10.5 and 21.00 Mbps) separately. The maximum throughput of the

case study is (21 Mbps) which represent a 100% throughput and the other cases represent (50%, 25%) of the maximum throughput.

3- The wireless(AP) continuously sent traffic with the selected throughput until the battery reaches 20% of its capacity. The results were shown in Figure (8).

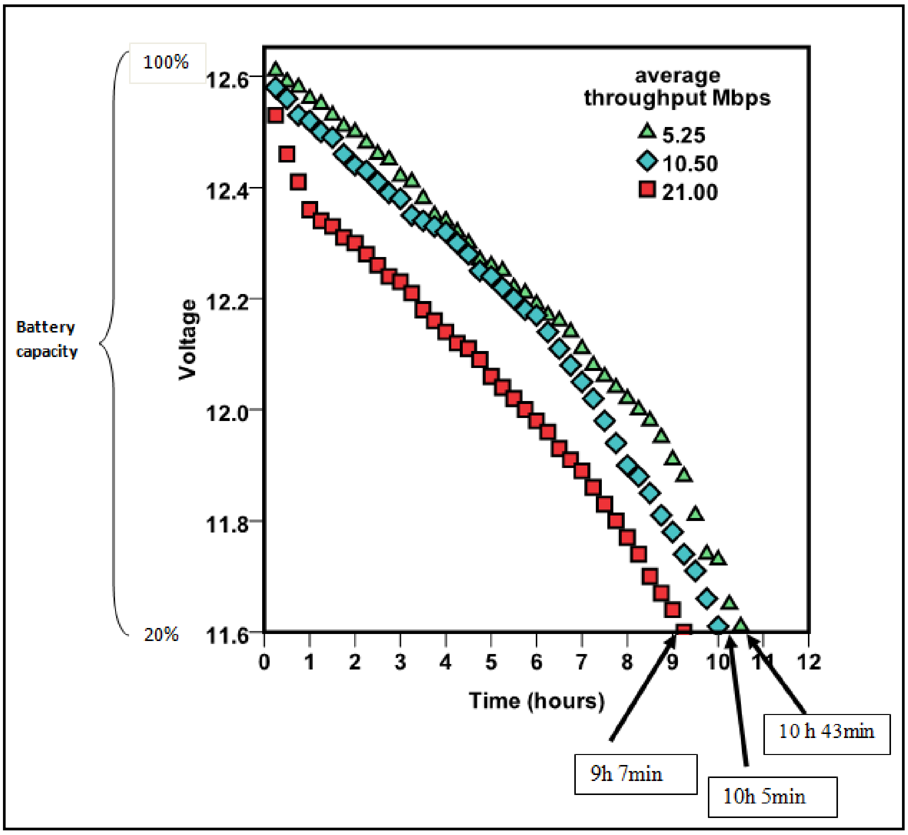



**Figure 8.** Trend of the battery discharge experiments

The discharge trend of 802.11g mode is determined experimentally to characterize the battery performance at various average throughputs, (i.e. 5.25, 10.50 and 21.00 Mbps). Independent variables that are held relatively constant are data rate (54) and the battery capacity. The discharge times at a voltage of about 11.6 V (voltage of 20% of battery capacity) under average throughputs 5.25, 10.50 and 21.00 Mbps, were, (9hours 7 min), (10hours 5 min) and (10hours 43min) respectively. From these results, we can conclude that, it is possible to extend the battery discharging time by about (1hour 36 min) by decreasing the throughput by (75%) and 58 min by decreasing the throughput by (50%) from the maximum throughput. This is an important factor in a wireless (AP) that works using the energy harvesting ; this extended battery time during the night will prevent the system from going to shut down for an additional hour keeping in mind that that the longest night in the investigated region is about (14) hours. Now at this instant, we need to derive a relation between the AE and the chosen

Traffic Rate (TFR) under certain environmental and networking conditions as follows:

$$AE = \text{Energy spent in (TX, RX, Idle periods)} \quad (15)$$

$$AE = TFR\left(\frac{I_{TX}}{Nr.\text{Data Rate}}\right) + TFR\left(\frac{I_{RX}.(Nr-1)}{Nr.\text{Data Rate}}\right) + TFR\left(\frac{I_{board}}{\text{AP Processing Speed}}\right) \quad (16)$$

where (Nr) ) is the RX to TX Traffic Ratio and AP Processing Speed reflects the data processing capabilities of the AP ( which is 50 Mbps for the Mikrotik 433AH platform [18]). Now, eq. (16) can be re arranged so that:

$$TFR = \frac{AE}{\left(\frac{I_{TX}}{Nr.\text{Data Rate}}\right)+\left(\frac{I_{RX}.(Nr-1)}{Nr.\text{Data Rate}}\right)+\left(\frac{I_{board}}{\text{AP Processing Speed}}\right)} \quad (17)$$

## 5. Conclusions

The main objective of this paper is experimentally measuring, analyzing and optimizing the energy consumption behaviors of IEEE 802.11a/b/g WLAN standards. This paper presents different methods for developing energy-efficient networking of IEEE 802.11a/b/g APs. We adopt the energy harvesting which can be helpful to develop future directions on “Green-Networking” research.. From the experimental results, the electrical current drained from the wireless (AP) varies by several factors such as 802.11 standards type, data rate, transmitting power level and traffic direction (In/Out). The results show that the highest data rates (modulation and coding schemes) use energy more efficiently than lower data rates in each of the 802.11a/b/g standards. Also, we can conclude that at the optimum conditions, the minimum power consumption can provides maximum throughput at specific wireless network environments. The choice of the most efficient energy standards among the 802.11a/b/g and their performance depends on the deployment requirements and applications. This study shows that the 802.11g provides an energy efficient choice and a good performance. This paper shows that it is possible to design a solar powered wireless (AP) with low cost and good performance using an experiment driven approach while utilizing historic network traffic and weather meteorological data. The proposed Battery Share Algorithm (BSA) technique provides a management to the battery capacity by sharing its capacity between the users associated to the solar powered wireless (AP). It is possible to extend the battery discharging time for the battery that supplies the solar powered wireless (AP) by using suitable traffic control algorithm.

## References


1. Ali Q.I., Jalal J.Kh., (2014) Practical Design of Solar Powered IEEE802.11 Backhaul Wireless Repeater, IEEE DCA2014 Conference, China.
2. Ali Q.I., (2014) Design, Implementation & Optimization of an Energy Harvesting System for VANETS' Road Side Units(RSU), *IET Intelligent Transportation Systems*, 8(3).
3. Ali Q.I., (2011) Design & Implementation of a Mobile Phone Charging System Based on Solar Energy Harvesting, *IJEEE Journal*, 7(1).

4. Ali Q.I., Khalid J., (2014) Practical Design of Solar Powered IEEE802.11 Backhaul Wireless Repeater", DCA2014 Conference, China.
5. Badawy G., Hamilton A., (2008) Solar Powered WLAN Mesh Network Provisioning for Temporary Deployments Wireless Communications and Networking Conference.
6. Bodh Karve S., Kamble S., (2010) Building wireless repeater operated by solar power, International Conference and Workshop on Emerging Trends in Technology, 1016-1016 .
7. Chiaravalloti S., Idzikowski F., Budzisz L., ( 2011) Power consumption of WLAN network elements, Telecommunication Networks Group, TKN Technical Reports Series, Berlin.
8. EnOcean. *Perpetuum International Edition* 4(6). http://tinyurl.com/2lxbo5 (or www.enocean.com/fileadmin/redaktion/pdf/perpetuum/perpetuum_06_en.pdf), 2007.
9. Ferro Solutions, VEH-360: Evaluation Power System Specifications.
10. Karina G., Tinku R., (2013) Power Consumption inIEEE 802.11n and IEEE 802.11g Networks, 20–26, Online Conference on Green Communications, IEEE.
11. Murabito A., (2009) A Comparison of Efficiency, Throughput, and Energy Requirements of Wireless Access Points, University of New Hampshire Inter Operability Laboratory, WLAN Consortium March.
12. Mabell K., (2013) Energy Efficiency in Wireless Access Networks: Measurements, Models and Algorithms, PhD Thesis, University of Trento, Italy.
13. Park G., (2005) Overview of Energy Harvesting Systems (for Low-Power Electronics) Presentation at the First Los Alamos National Laboratory Engineering Institute Workshop: Energy Harvesting.
14. Paradiso J.A., Starner T., (2005) Energy scavenging for mobile and wireless electronics, *IEEE Pervasive computing*, 4(1), 18-27.
15. Reigadas F.J.S., Fernandez A.M., Garcia P.O., Escola F.R., Pascual J.S., (2008) The design of a wireless solar-powered router for rural environments isolated from health facilities, *IEEE Wireless Communications*, 15(3).
16. Roundy S., (2003), Energy scavenging for wireless sensor nodes with a focus on vibration-to-electricity conversion, (Doctoral dissertation, University of California, Berkeley). http://tinyurl.com/2s8khk.
17. Park C., Chou P., (2004) Power utility maximization for multiple-supply systems by a load-matching switch, Proc. ACM/IEEE International Symposium on Low Power Electronics and Design, 168–173.
18. RouterBOARD 433AH Series (2009), MikroTik SIA ,User's Manual.
19. Shellsolar INC., ST40, ST20 module product information sheet, available at:www.shellsolar.com.

## Appendix (A): The selected Solar Panels ST20

## Electrical Characteristics

**Data at Standard Test Conditions (STC)**

STC: irradiance level 1000W/m², spectrum AM 1.5 and cell temperature 25°C

| | | |
|---|---|---|
| Rated power | $P_r$ | 20W |
| Peak power | $P_{mpp}$ | 20W |
| Peak power voltage | $V_{mpp}$ | 15.6V |
| Open circuit voltage | $V_{oc}$ | 22.9V |
| Short circuit current | $I_{sc}$ | 1.54A |
| Minimum peak power | $P_{mpp\ min}$ | 18W |

The abbreviation 'mpp' stands for Maximum Power Point.

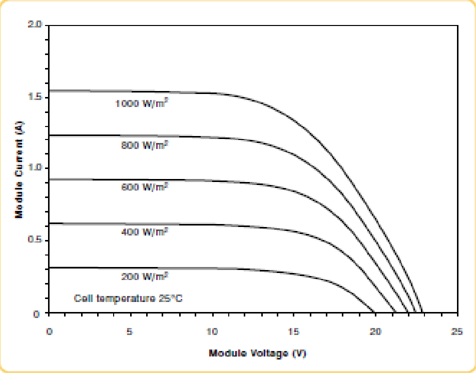
**Typical data at Nominal Operating Cell Temperature (NOCT) conditions**

NOCT: 800W/m² irradiance level, AM 1.5 spectrum, wind velocity 1m/s, $T_{amb}$ 20°C

| | | |
|---|---|---|
| Temperature | $T_{NOCT}$ | 47°C |
| Mpp power | $P_{mpp}$ | 14W |
| Mpp voltage | $V_{mpp}$ | 13.7V |
| Open circuit voltage | $V_{oc}$ | 20.2V |
| Short circuit current | $I_{sc}$ | 1.2A |

## Typical I/V Characteristics

The I/V graph below shows the typical performance of the solar module at various levels of irradiance.




The I/V graph below shows the typical performance of the solar module at various cell temperatures.