Daily throughput and energy efficiency analysis of campus WLAN

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***Abstract*— With a services like Voice over IP (VoIP), Media on Demand, Internet Protocol TeleVision (IPTV), demands for throughput in campus wireless local area networks (WLAN) increase. As a result, energy efficiency of WLAN equipment has become an issue, due to necessity for installing high number of access points (APs) which will accommodate throughput demands for such services. In this paper, firstly throughput data in real outdoor campus WLAN are analysed. Secondly, estimated energy efficiency of campus outdoor APs are presented. Results provide insight into daily throughput and energy-efficiency distribution in conditions of average and peak wireless network traffic. Obtained results will help in defining energy efficiency parameters for WLANs of "green campuses", which will be integral part of future heterogeneous networks.**

Keywords—campus, throughput, wireless, network, WLAN, energy-efficiency, access point, green, power

I. Introduction

Nowadays wireless local area networks (WLAN) are standard part of the IP network infrastructure at university campuses all around the world. In this paper, real campus WLAN network is analyzed in a manner of consumed daily throughput and resulting energy efficiency. Firstly, the average and maximum values of throughput per access point are given, then estimated energy efficiency is presented. Energy efficiency is estimated based on the real-time throughput data collected from the monitoring systems.

Analyzed network is outdoor WLAN campus network that serves clients at campus of the University of Split, Croatia. The network is part of Eduroam service (an international roaming service for users in higher education and research). It is realized in co-operation of University of Split and Croatian Academic and Research Network - CARNet. Wireless network consists of 15 wireless access points (APs) in full mesh topology, controlled by wireless controller. APs are connected to high-speed core of the CARNet network using gigabit links through closest customer premises equipment (CPE). Network covers 5 locations on approximately 60,000 m^2 of land. Average number of installed outdoor APs per location is three, where each location represent premises of one University institution (faculty, student dormitory, etc.).

Although in the given network there are 15 campus APs, due to technical constraints data for one of them cannot be collected by monitoring systems, so the data of 14 APs are analyzed. However, the AP that is not included in analysis does not affect results presented in this paper. The rest of the paper is organized as follows: related work focused on parameters of campus WLAN are presented in Section 2. In Section 3, daily throughput analysis is presented (average and maximum daily throughput (traffic) that is used per AP of outdoor campus WLAN). Section 4 presents graphs of throughput per AP. Section 5 gives results of estimating energy-efficiency (W/Mbps) of APs based on real throughput and nominal power consumption of installed APs. Section 6 gives some concluding remarks.

II. Related Work

Considering a need for user's mobility in campus area as well as growing number of users of campus, planning throughput and achieving energy efficiency of campus WLAN network become crucial. Authors in [1] studied energy consuming characteristics of large-scale campus WLAN. It was concluded by the authors that energy-saving mechanisms must consider powering off APs. In [2], a traffic and power consumption relationship on a WLAN is discussed. Also, a packet length is included in a model along with throughput and power in [3]. Experimentally measured energy consumption of an AP is presented in [4]. Since throughput of served users varies during time, level of AP energy efficiency expressed in W/Mbps become a valuable parameter in estimating AP performance.

III. Daily Throughput Analysis

Real throughput data presented in this section are collected from Zenoss open-source monitoring software that collects data about network traffic constantly in time (24/7). Throughput of any single AP depends on the number of users in a given point of time. Number of users served by each AP depends on users mobility as well as on period of the day. At some point of the day, some access points have zero users associated to them (e.g. cafe bar, library, student's dormitory, offices during night periods). That resulted with minimal traffic during some time intervals, so it was reasonable to present averages and maximums of throughput per AP. Daily pattern presenting number of simultaneously connected clients for given campus WLAN infrastructure is shown in Figure 1. This figure presents daily variations of the total number of connected clients during a day for complete WLAN campus network. Table 1 gives locations of access points at the university campus.

A. Maximum Daily Throughput per Access Point

Throughput is collected every day by the network monitoring system on the 5 minute time basis. Maximum throughput is maximum value that is given by monitoring system for the desired time period. Throughput of every AP in the campus WLAN network directly depends on the number of users that

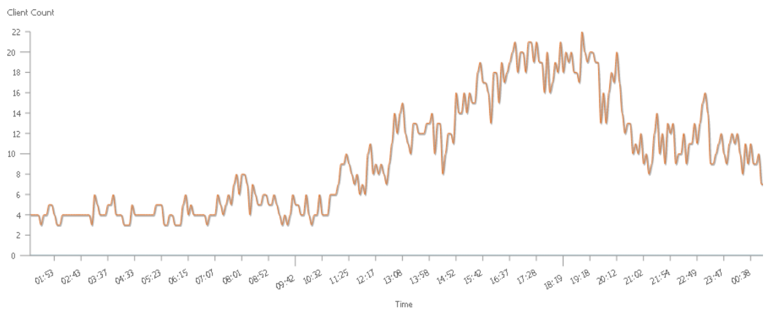

Figure 1: Daily number of WLAN clients

Table 1: Locations of AP

AP No.	Location of analyzed AP
AP 01	Faculty of Electrical Eng., Mechanical Eng. and Naval Architecture
AP 02	Faculty of Electrical Eng., Mechanical Eng. and Naval Architecture
AP 03	Faculty of Electrical Eng., Mechanical Eng. and Naval Architecture
AP 04	Faculty of Science
AP 05	Faculty of Science
AP 06	University Library
AP 07	University Library
AP 08	Faculty of Economics
AP 09	Faculty of Economics
AP 10	Faculty of Economics
AP 11	Campus Dormitory
AP 12	Campus Dormitory
AP 13	Faculty of Civil Eng., Architecture and Geodesy
AP 14	Faculty of Civil Eng., Architecture and Geodesy

are associated to that AP during some point of time. It varies throughout the day for different reasons such as location of AP throughout the day for different reasons such as location of AP and period of the day. Location is relevant because in some periods of the day, for example, APs near cafe bar or campus dormitory will serve more users than APs near faculty buildings. It is also reasonable that at night it will be less users than during day in the areas near classroms or campus staff offices. Maximum throughput distribution through APs is shown in Figure 2.

B. Average Daily Throughput per Access Point

In order to collect information's about average daily throughput per AP, data are gathered from all SNMP enabled interfaces in the network on 5 minutes basis. As a result of that process, average throughput is calculated automatically for time interval that is given. In case of this analyses, the time interval is 1 day. Average daily throughput is obtained based on average inbound and outbound traffic. Calculation of average daily throughput per AP is performed by summing average inbound and outbound throughputs.

Maximal and average throughputs measured for every of analysed APs are shown in Figure 2 and 3, respectively.

From Figures 2 can be noticed that average throughput for analysed APs is not uniformly distributed, which is quite understandable since measured results present real traffic patterns obtained on fully operational campus WLAN. Many

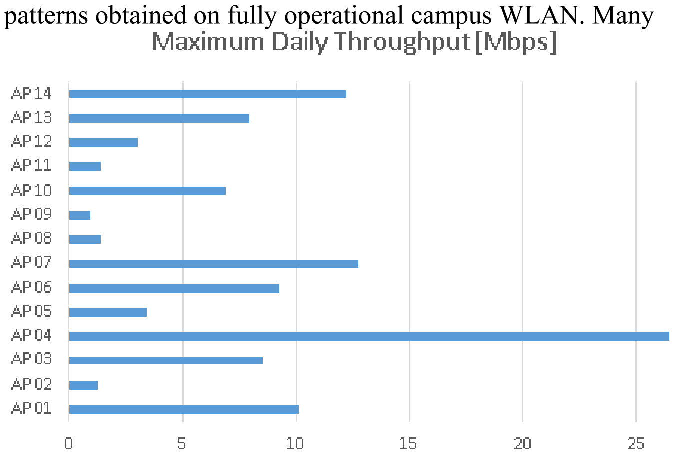

Figure 2: Maximal throughput distribution for analyzed APs

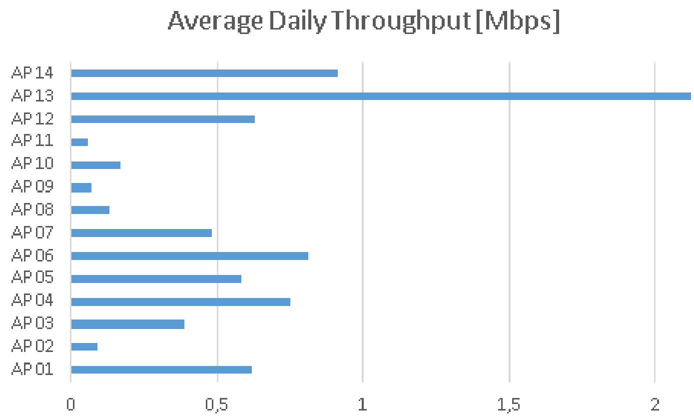

Figure 3: Average throughput distribution for analyzed Aps

factors affect throughput as well as AP traffic pattern shape such as: user mobility, day/night users behaviour, etc. Additionally, due to constant trend of campus expenditure, students and teaching staff number increase and it is reasonable to assume that with more users who will use campus WLAN in near future, throughput distribution per AP will be distributed even more non-uniformly. However, this will impact on increase of average and maximal WLAN AP utilization. WLAN AP utilization has its effect on energy efficiency which is discussed in Section 5 of this paper.

IV. THROUGHPUT DATA PER AP

In this section, inbound and outbound throughput data per AP are given in period of 24 hours, from 09 June 11 PM to 10 June 11PM (Table 3). For the analyses, we have selected a typical working day, which traffic pattern variations can be representative for other working days throughout the year. Outbound traffic is downstream from the client's perspective (from AP to client), while the inbound traffic is upstream from the client's perspective (from client to AP). This approach will give better insight in the traffic patterns of the analysed network. In Table 2, detailed data about inbound and outbound throughput are given, for the case of average and maximum daily throughput.

As it can be seen minimum inbound and outbound throughputs are not included in Table 2 for the obvious reason, since in reality every access point at some period of 24 hours interval has throughput 0 Mbps, so all the minimums are zero. Also from the results given in Table 3, it is evident that average throughput is rather low. There are various reasons for that and the main, of course, is rather small number of users that are using the network at this moment. However, significant increase in number of users is expected at campus locations in near future, hence investment in robustness and redundancy of campus WLAN is very reasonable.

Table 2: Throughput per AP

Access Point	Average Throughput Inbound/Outbound [Mbps]	Maximum Throughput Inbound/Outbound [Mbps]
AP 01	0.13/0.49	2.05/8.03
AP 02	0.01/0.08	0.1/1.13
AP 03	0.04/0.35	0.67/7.87
AP 04	0.14/0.61	5.89/20.58
AP 05	0.06/0.51	0.31/3.14
AP 06	0.12/0.69	1.01/8.23
AP 07	0.03/0.45	1.03/11.72
AP 08	0.02/0.11	0.15/1.23
AP 09	0.01/0.05	0.15/0.8
AP 10	0.03/0.14	0.73/6.15
AP 11	0.01/0.05	0.26/1.1
AP 12	0.06/0.57	0.32/2.69
AP 13	0.18/1.94	0.8/7.12
AP 14	0.08/0.82	0.73/11.48

Due to nature of users habits in communication, outbound traffic is in most cases higher than inbound traffic.

From Table 2, it is evident that AP04 has the highest maximum value of daily inbound as well as outbound traffic. AP04 covers area that is of big interest in daily mobility of users, because its location is on the building of Faculty of Science. It covers large space near the Faculty that has significant amount of students and also covers the space of cafe bar.

AP09 has the lowest daily maximum value of inbound as well as outbound traffic. AP09 covers north area near the Faculty of Economics that has low concentration of users. For all Aps, average throughput correlates with maximum throughput very well. Every AP in the network has some periods during a day with zero traffic which is logical to happen in real life conditions. In Figures 4 – 17, daily traffic patter variation for each of analysed AP is presented.

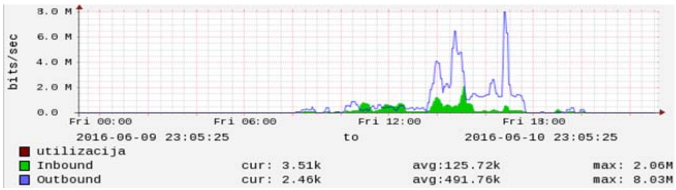

Figure 4: AP01 throughput

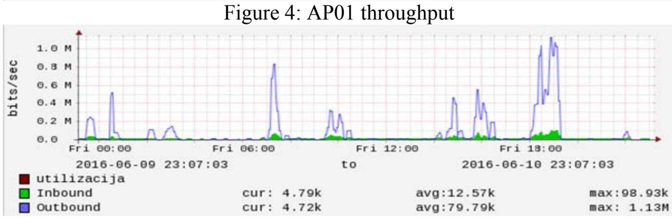

Figure 5: AP02 throughput

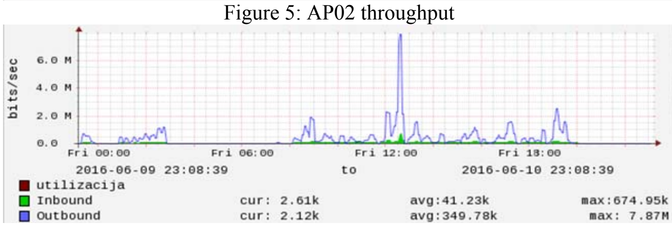

Figure 6: AP03 throughput

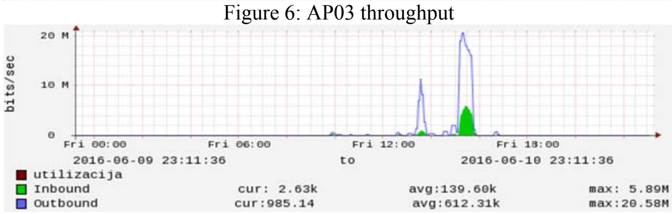

Figure 7: AP04 throughput

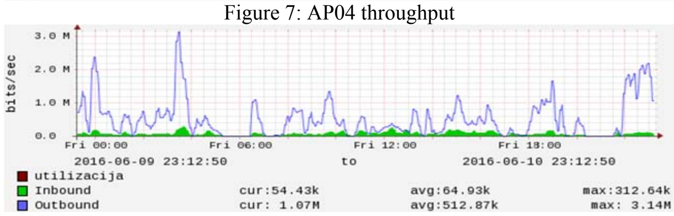

Figure 8: AP05 throughput

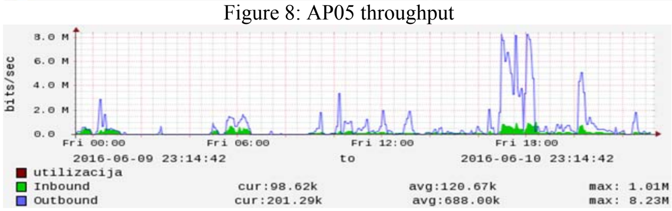

Figure 9: AP06 throughput

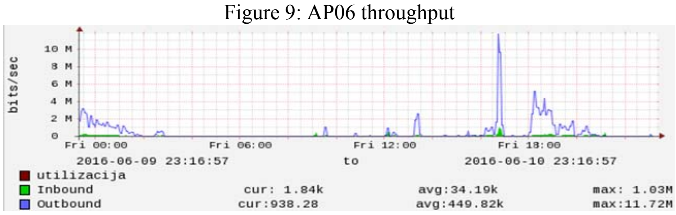

Figure 10: AP07 throughput

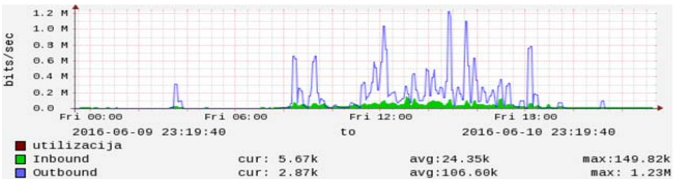

Figure 11: AP08 throughput

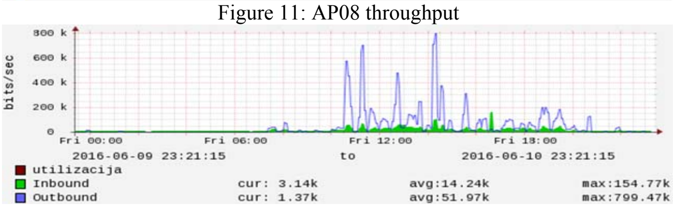

Figure 12: AP09 throughput

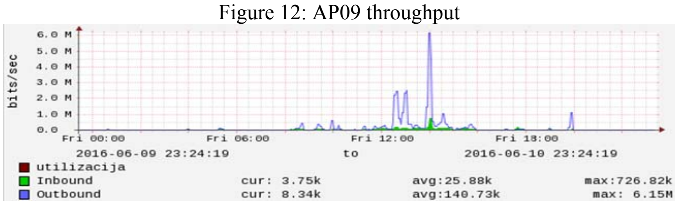

Figure 13: AP10 throughput

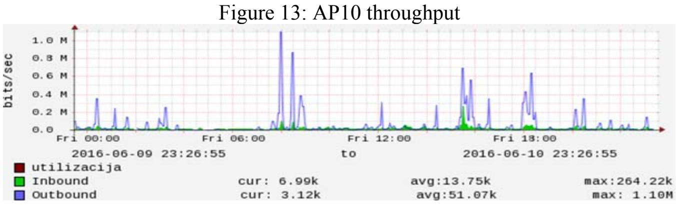

Figure 14: AP11 throughput

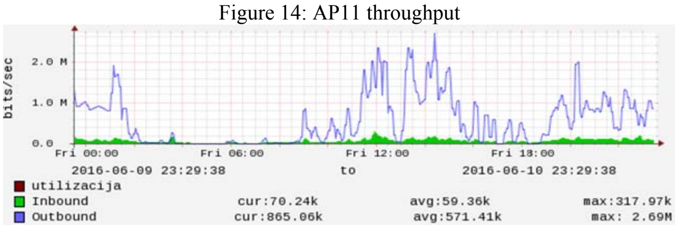

Figure 15: AP12 throughput

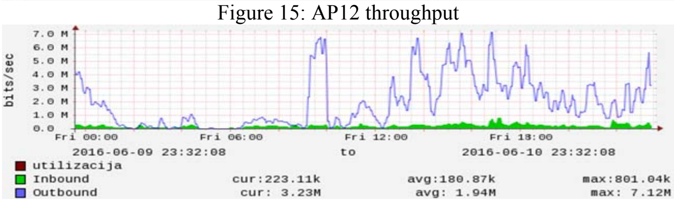

Figure 16: AP13 throughput

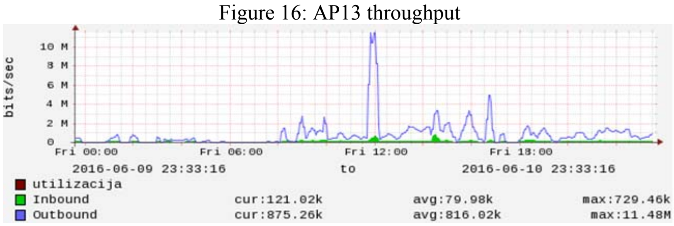

Figure 17: AP14 throughput

V. Estimated Energy Efficiency per AP

Generally, energy efficiency is defined by the relation:

$$\text{Energy Efficiency} = \frac{\text{Power Consumption } [\text{W}]}{\text{Throughput } [\text{bps}]} \qquad (1)$$

which gives estimation of daily average and maximum energy efficiency of the APs. According to [5] and Table 3, nominal power consumption of analysed AP in is 67 W. In this paper, energy efficiency [W/bps] is estimated using constant nominal power consumption value given by vendor and instantaneous values of average and maximum daily throughput of the APs presented in Figures 2 and 3, respectively. Technical characteristics of analysed APs (Cisco Aironet 1550 Series Outdoor AP) are given in Table 3. Various technical properties are presented and for the green campus WLAN, the most important are Maximum Transmit Power (Tx),

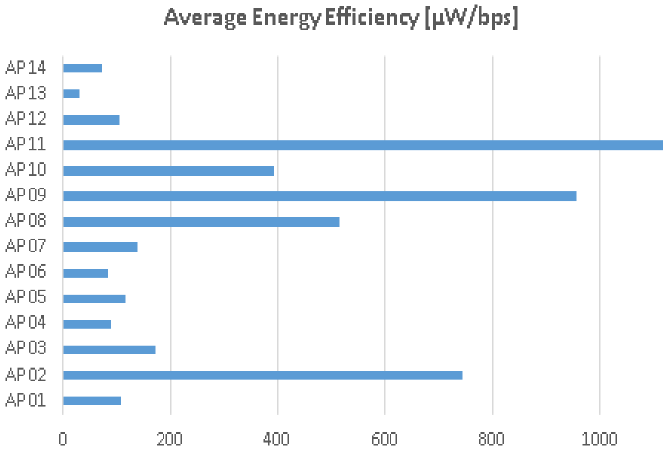

Figure 18: Average energy efficiency distribution through APs

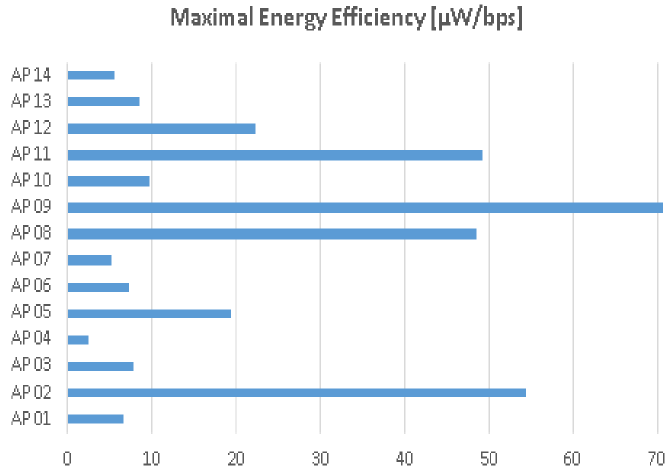

Figure 19: Maximum energy efficiency distribution through Aps

Environmental Variables and access point Power Consumption. All that variables together with overall bandwidth and energy efficiency should be taken into consideration in process of developing greener campus networks as part of next generation networks (NGN). During analyses, impact of different AP transmit (Tx) power levels on power consumption was neglected. This is because the Tx power of analysed APs was constant in time, and it was set to maximal value of 28 dBm (Table 3).

A. *Estimated Average and Maximal Energy Efficiency per Access Point*

Average energy efficiency distribution of analysed APs is shown in Figure 18 energy efficiency is calculated according to relation (1), with average throughputs used in calculation.

Table 3: Technical characteristics of APs

<table>
<tr><th>Technical Property</th><th colspan="2">Specification</th><th>Technical Property</th><th colspan="2">Specification</th></tr>
<tr><td>802.11n</td><td colspan="2">● 2x3 multiple-input multiple-output (MIMO) with two spatial streams
● Legacy beamforming
● 20- and 40-MHz channels
● PHY data rates up to 300 Mbps
● Packet aggregation: A-MPDU (Tx/Rx), A-MSDU (Tx/Rx)
● 802.11 dynamic frequency selection (DFS)
● Cyclic shift diversity (CSD) support</td><td>Max. Transmit Power</td><td>2.4 GHz
● 802.11b (CCK)
◦ 28 dBm with 2 antennas
● 802.11g (non HT duplicate mode)
◦ 28 dBm with 2 antennas
● 802.11n (HT20)
◦ 28 dBm with 2 antennas</td><td>5 GHz
● 802.11a
◦ 28 dBm with 2 antennas
● 802.11n non-HT duplicate (802.11a duplicate) mode
◦ 28 dBm with 2 antennas
● 802.11n (HT20)
◦ 27 dBm with 2 antennas
● 802.11n (HT40)
◦ 27 dBm with 2 antennas</td></tr>
<tr><td>Data Rates Supported</td><td colspan="2">802.11a: 6, 9, 12, 18, 24, 36, 48, and 54 Mbps
802.11g: 1, 2, 5.5, 6, 9, 11, 12, 18, 24, 36, 48, and 54 Mbps
802.11n data rates (2.4 GHz): 130
802.11n data rates (5 GHz): 270</td><td>Network interfaces</td><td colspan="2">● 10/100/1000BASE-T Ethernet, autosensing (RJ-45)
● Fiber SFP (1552E/EU/H)
● DOCSIS/EuroDOCSIS 3.0 (8x4) Cable modem interface (1552C/CU)</td></tr>
<tr><td>Maximum Number of Nonoverlap. Channels</td><td>2.4 GHz
● 802.11b/g:
◦ 20 MHz: 3
● 802.11n:
◦ 20 MHz: 3</td><td>5 GHz
● 802.11a:
◦ 20 MHz: 19
● 802.11n:
◦ 20 MHz: 19
◦ 40 MHz: 11</td><td>Environ.</td><td colspan="2">Operating temperature: -40 to 55°C (-40 to 131°F) plus Solar Loading
Storage temperature: -50 to 85°C (-58 to 185°F)
Wind resistance: Up to 100-MPH sustained winds, Up to 165-MPH wind gusts</td></tr>
<tr><td>Power Consumption</td><td colspan="5">67 W</td></tr>
</table>

Maximal energy efficiency distribution of analysed APs is shown in Figure 19. Maximal energy efficiency is calculated according to relation (1), with maximal throughputs used in calculation. As it can be seen form Figures 4 and 5, average and maximal energy efficiency significantly varies for the same AP and even among all APs. This variations are consequence of different number of users served by particular AP in the network. It is known that number of users served by some AP, significantly impacts on overall throughput which is higher when lover number of users are simultaneously served by AP and vice versa. This impacts on AP energy efficiency, which is higher in terms of W/bps for lower number of served users and vice versa. Hence, from Figures 4 and 5, it can be seen that average energy efficiency of single AP ranges between 50 µW/bps and 1100 µW/bps, and for maximal energy efficiency, it ranges between 30 µW/bps and 71 µW/bps. It is necessary to emphasize that obtained values of energy efficiency are specific for analysed AP type and for such traffic patterns, which are relatively low due to underutilised throughput capacity of analysed campus WLAN network. If traffic patterns will be characterised with higher number of simultaneously served users, average values of energy efficiency parameter (µW/bps) will be higher, due to lower instantaneous throughputs.

VI. Conclusion

In this paper, real throughput data of outdoor campus WLAN is analysed in order to correlate its relationship with estimated energy efficiency. Throughput is collected in real-time from 14 AP of campus WLAN. Based on a given throughput, energy efficiency of the APs is estimated. Two cases of energy efficiency are presented. Firstly, energy efficiency based on average network throughput, and secondly energy efficiency in conditions of maximum throughput per AP. Results show that energy efficiency values are not uniformly distributed along all APs and that is because different APs on different locations have different traffic patterns. Additionally, obtained results show that energy efficiency is lower in conditions of lower instantaneous AP throughput values than for the cases of higher (maximal) throughput values. This is consequence of higher AP throughput values in WLAN when number of simultaneously served users are lower and vice versa. Our future research activities will be focused on analyses of impact of weekly and monthly campus WLAN traffic pattern variation on energy efficiency of APs.

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