Utilizing Communication Air-Time to Reduce Energy Consumption of Access Points

Ozgur Ozkaya, Jetmir Haxhibeqiri, Ingrid Moerman, Jeroen Hoebeke
IDLab, Ghent University - imec
name.surname@ugent.be

***Abstract*—With the advancement of communication technologies, network densification, the number of connected devices, and high-demand throughput applications are increasing as well. As such communication networks are becoming power-hungry increasing the need for new power resources to support them. To reduce the impact on the environment such power-hungry networks either should be powered by renewable power resources or should be able to harvest the energy locally, or reduce the energy consumption by improving communication design. Access points (AP) are one of the network elements that are highly distributed and where energy consumption can be reduced with better design and communication models. In this paper, we propose a new method that utilizes unused time periods in active communication to allow an AP to go on idle mode without exceeding the traffic latency bounds or affecting the packet loss ratio. To simulate the scenarios, we used ns-3 system-level simulator. The presented results demonstrate the possibility of energy savings that is proportional to the AP standby time, and in some cases, it can go up to 90% compared to the energy consumption of normal operation. In addition, the energy savings are calculated for some commercial APs to see how much energy can be saved by utilizing the proposed method.**

***Index Terms*—access points, energy saving, wifi, time-sensitive networking**

I. Introduction

Increased energy consumption is one of the main concerns of our era, that is being addressed either by increasing renewable energy sources or reducing the energy consumption of appliances by design. As such the impact of energy consumption on the environment will be limited. As one of the fastest growing sectors, Information and Communication Technology (ICT) is also one of the most power-hungry. It is estimated that by 2030 the ICT sector will account for 21% of the world's energy consumption in the best case and up to 51% in the worst-case scenario [1]. Part of this consumption will be used to run big data centers and internet infrastructure, and part of it for supporting communication access networks.

Communication networks have ever-increased in the services they provide and the number of end nodes that are connected to the network. In the annual report of Cisco [2], it is predicted that there will be 3.6 wireless devices per capita by 2023 in the world. This in return poses a need for densification of the access network by installing a higher number of APs, increasing further energy consumption. According to [3], more than 80% of all wireless traffic is created or terminated indoors, where Wi-Fi is primarily used. As such, wireless networks are becoming more and more common for different use cases, thanks to the recent developments in IoT, cellular networks (5G/6G/xG), and Wi-Fi [4, 5].

Until now the focus was given to decreasing the energy consumption of wireless end devices. To this end, different methods are proposed, e.g. by setting end nodes on idle or deep sleep mode like power saving mode in WiFi or cellular networks [6], uplink-triggered downlink like in LoRaWAN networks [7], etc. Contrary, the access network is required to be operational all the time. According to the IEEE 802.11 standard, APs must not enter sleep mode, even when the load is low or non-existent. This leads to energy waste on weekends, holidays, and after working hours [8].

The main contribution of this paper is the newly proposed method to reduce the energy consumption of APs. In many cases, the AP is not busy transmitting or receiving data traffic, rather being busy only with beacon traffic and other control traffic. In this work, we exploit the unused air time by the AP, by combining it in longer time periods where the Wi-Fi module of the AP can go to standby mode. As a result, APs consume less energy than in a fully operational state. To achieve this, the end devices should be informed about the times when the access point is not accessible. Clock synchronization and avoiding possible packet loss in uplink due to AP inactivity can be handled by time-sensitive networking (TSN) synchronization and scheduling mechanism. The IEEE 802 TSN task group [9] created a set of standards called TSN to facilitate deterministic communication over Ethernet networks. With the developments of the TSN concept for wireless networks, W-TSN [10] such features are available for Wi-Fi as well.

The rest of the paper is organized as follows. Section II reviews the related works in the literature. The proposed model is explained in Section III together with the energy consumption model. Section IV gives the performance analysis in terms of impact on communication latency, number of aggregated packets, and overall energy consumption reduction. Section V concludes the paper.

II. Related Work

According to [11], we can divide energy saving approaches into 5 categories: i) improving the energy efficiency of hardware components, ii) turning off components selectively, iii) energy efficiency of radio transmission process optimization, iv) heterogeneous cells, and v) adopting renewable energy sources. Since this paper focuses on reducing the energy consumption of APs through better communication design, this section will focus on works related to the second and third categories. Works related to both Wi-Fi networks and cellular networks are considered.

In [8] Silva *et al.* focus on turning off the radio automatically when no device is associated with the APs. They provide a learning system that utilizes network data to accumulate knowledge over time. In order to determine whether an AP shuts off its radio or not, they use the data gathered from the network. Ghosh *et al.* in [12] provides a technique to reduce the energy consumption of an LTE network by setting selected base stations in sleep mode. To give service to the clients of slept BSs, modifications on other BSs are done such as antenna tilting angle, height, and transmit power increase. Similarly, in order to conserve energy in a cellular network, Samdanis *et al.* [13] suggested a self-organized network (SON) that turns off certain BSs. The amount of load, which depends on the number of clients connected and the radio resources, determines this choice. The main goal of work in [13] is to turn off as many BSs as possible during non-peak times.

Kholaif *et al.* [14] presented a method of a power saving AP without violating quality-of-service (QoS) requirements. The proposed work uses a network allocation map (NAM) to share the superframe, e.g. beacon interval, of an AP with the clients. NAMs are sent with periodic beacons and thus traffic is coordinated among nodes. When real-time traffic is present the AP schedules its sleeping pattern according to clients' QoS requirements. In [15], Ogawa proposed a cross-layer queuing control method for saving power. The main focus of work in [15] is to keep the MAC queue empty since AP can not switch to sleep mode unless the MAC queue is empty. Layer 3 dequeuing mechanism is exploited to achieve power saving.

Contrary to works in [8, 13, 12] in this paper we propose to send APs in standby mode, on a time basis, based on unused air time by the APs. On the other hand, commercial solutions [16, 17]focus on power saving mechanisms for off-peak hours, leaving out the energy saving mechanism during the operational time which is considered in this paper. Furthermore, we utilize the WiFi features of packet aggregation, to increase the time frame when the APs can be set to standby mode.

III. Communication Air-time Utilization Method

In this section, the utilization communication air-time (UCAT) method to decrease the energy consumption of APs is described in detail.

A. Methodology

Even when there are no or few clients and communication with/from AP is scarce an AP must be operational by transmitting beacons and other control traffic, while the rest of the time will be in the receiving mode. Moreover, the channel access mechanism in WiFi is based on the Carrier Sense Multiple Access with Collision Avoidance CSMA/CA mechanism, which relies on randomness resulting in small chunks of air time in between packets that are not used by devices. While AP is operational all the time, these small chunks of unused air-time result in unnecessary energy consumption by AP. By utilizing these small unused air times, an AP can decrease its energy consumption. Our approach seeks to combine unused air times to form longer time periods over a cycle during which AP can be set on standby mode, without going increasing the communication latency beyond certain levels. The cycle time over which an AP can go to standby mode can be smaller than the beacon interval, such as 32 or 64 milliseconds, with standby percentages of 25% of the cycle. As such, the amount of energy saving is highly dependent on the unused air time percentage during one cycle.

Air time usage percentage depends on the network load, which is proportional to the amount of traffic sent by each node and the number of nodes attached to AP. We used ns-3 simulations to determine air time usage percentage for different numbers of nodes connected to a single AP, as shown in Figure 1. Each client transmits 512 bytes long packets, with an application layer data rate of 4 Mbps. As the number of clients grows, air-time usage increases also, however, even in the worst-case scenario, air-time usage does not pass 80%. When the network load increases, each node has to wait longer before it accesses the channel. This relates to the contention window (CW) size based on which the waiting time is randomized. For each unsuccessful re-transmission, the size of the CW limit is doubled, moving to the next level of CW, starting from a minimum of 15 to a maximum of 1023. In more than 95% of cases, the contention window drawn is from the first level when the network load is low. On the other hand, when the network load is highest, the CW is drawn from the first level only in ∼70% of cases, ∼20% from the second level, and the rest from other levels. The relation between the CW, network load, and air-time usage is shown in Figure 1.

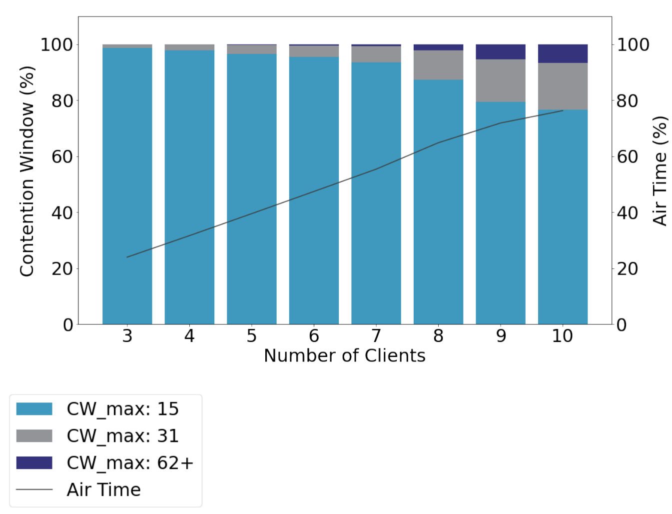


Fig. 1: An example of air-time and contention window chart

By shrinking the traffic in smaller transmission periods the contention might increase. To overcome this, packet aggregation can help in decreasing the number of channel access needed for the same amount of data transmitted. Moreover, when the traffic is buffered during the standby mode of the

AP, packet aggregation is even more beneficial, achieving thus the same amount of contention compared to the case when the AP does not go to standby mode.

W-TSN provides time synchronization and a scheduled access mechanism for wireless clients [10]. Without W-TSN, clients can transmit data in uplink during times when the AP is on standby mode. Therefore, notifying clients about standby state times and forcing them to stop sending during these periods wouldn't be possible. To simulate this we used ns-3 simulator to take advantage of synchronized time. By preventing all nodes from accessing the channel for a period of time during the cycle, sufficient time is created for the Wi-Fi module to go into standby mode. As a result, all nodes are able to use the medium only for a fraction of a communication cycle. Figure 2b depicts the outcome of the example scenario with cycles of 32ms. As it is seen, there is no transmission during the last quarter of each cycle compared to the default Wi-Fi version in figure 2a. These reserved times are used to switch to standby mode, hence reducing energy consumption.

B. Energy Consumption Model

Total energy consumption is the combination of energy usage in different states as shown in equation 1 [11]:

$$TotalEnergy = P_{active} + P_{idle} \tag{1}$$

Let i be the possible standby time percentage, X be the energy used by AP in an active state, and r be the reduction of energy consumption during the standby state, then:

$$TotalEnergy = (1 - i) * X + i * X * (1 - r) \tag{2}$$

The energy saving percentage can be calculated as the ratio of the total energy when using UCAT-AP to the total energy when using conventional AP, as given in equation 3:

$$\alpha = (1-(((1-i)+i.(1-r)))*100; 0 < r < 1; 0 < i < 1; \tag{3}$$

Equation 3 shows that the energy saving percentage α is dependent on the standby energy consumption percentage of the Wi-Fi module r and standby time percentage i.

IV. Simulation Parameters and Results

In this section, detailed information about simulations is given. Following that, the proposed method's results are compared to the default Wi-Fi. Potential energy saving results and the effect of the proposed method on commercial devices are discussed.

A. Simulation Parameters

The simulations have been run using ns-3 v3.36.1 on Ubuntu 22.04 Linux distribution operating system. All parameters of the simulations are stated in Table I.

All of the clients are distributed randomly within a 12x12 meter area, with an AP in the center of the area. This configuration allows all the clients to hear each other. Thus, the hidden terminal problem that occurs in wireless networks is avoided. As a result, RTS/CTS mechanism is not needed before transmission. After 2 seconds, all nodes launch their CBR application, with small intervals, to send packets to the AP with the given parameters. To generate randomness among clients, normal distribution function, from ns-3, is used to determine packet size and data rate. Mean values of the distribution are given in the table I. Bound values are selected as 256 and variances are 1024 and 2048 for data rate and packet size respectively. At the start of each cycle, nodes select a random packet size and data rate value for that cycle. We did scenarios with 3, 7, and 10 clients, respectively.

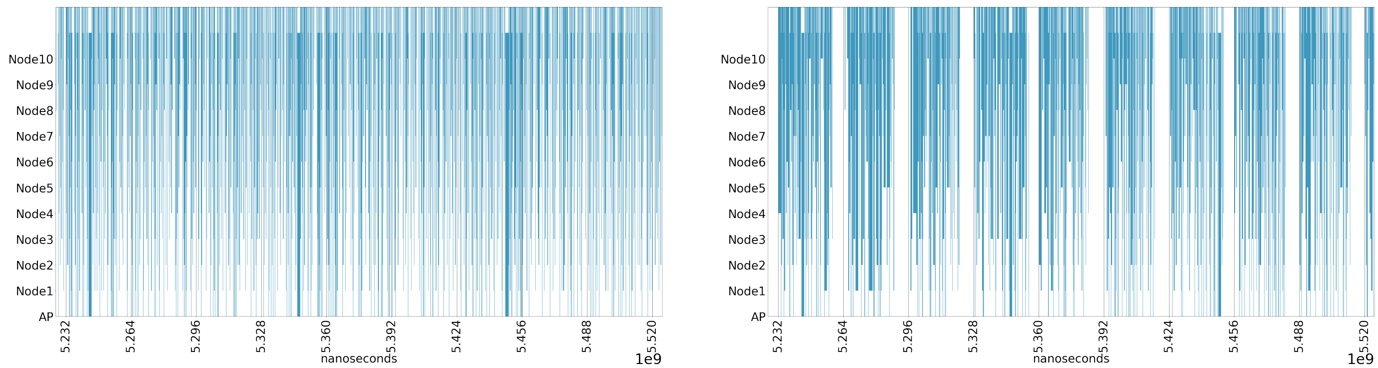
TABLE I: Simulation Parameters

Name	Value
Area of simulation	12x12 meters
AP location	Center (6,6)
PHY data rate	64 Mbps
Mean application data rate	512-1024-2048 kbps
Mean packet size	512-1024 bytes
Number of clients	3 - 7 - 10

B. Results

The results presented are for a single-hop wireless network model. We run different network simulations with various network loads, including very low network load (less than 20% air time usage), low network load (between 20% and 40% air time usage), and medium network load (between 40% and 60% air time usage). The remaining conditions are high network load and very high network load. Both have more than 60% air time, which is beyond the scope of this paper because there is too much contention and it is difficult to create enough time frame where we can put the Wi-Fi module of the AP to standby mode. When the UCAT method is used to decrease energy consumption in our simulations, AP is set on standby mode for 25% of the communication cycle.

Figure 3 shows the delay comparison between default Wi-Fi operation and the UCAT method for two different communication cycles, 32ms and 64ms, respectively. The results in Figure 3 are presented with their respective confidence intervals. The bottom and the top bounds of the colored rectangles show the 5 percentile and 95 percentile respectively. The orange line inside the rectangles indicates the mean value of the given result. The extreme black lines represent the maximum and minimum delay values. It can be stated that the confidence intervals do not depend on the simulation time, but on the achieved measured latency. In the case of the very-low load scenario, we used 5 clients, each of them transmitting packets with an average size of 512 bytes and an average application data rate of 512 kbps over one cycle. With standard Wi-Fi, the average delay was 0.2 ms, while the average delay using the UCAT method was 1.9 ms and 2.9 ms for 32 ms and 64 ms communication cycles, respectively. For the low-load scenario, we used 7 clients, each of them sending 512-byte packets on average, with an average application data rate of 1 Mbps. The average delay of the default Wi-Fi was 0.2 ms. With the UCAT method, the average delay of 1.6 ms for a 32 ms communication cycle and 2.7 ms for a 64 ms cycle scenario was achieved. A medium-load network scenario was emulated



(a) A network with no energy saving mechanism

(b) A network with UCAT-AP

Fig. 2: An example of air time usage

with 10 clients, each sending packets of 1 KB size and 2 Mbps application data rate on average. In default Wi-Fi, packets are sent with an average delay of 0.5 ms. The average delay with the proposed method was 4 ms and 7 ms for 32 ms and 64 ms communication cycle, respectively. The packet loss ratio was 0% in all cases. The communication delay is higher when UCAT is used, nevertheless, it can be controlled by setting a smaller communication cycle during which the AP is set in standby mode. It is seen that even in the medium network load the communication delay is proportional to energy saving time, and in any case does not exceed the standby mode time period (e.g. 25% of the cycle time, 8 ms and 16 ms, respectively).

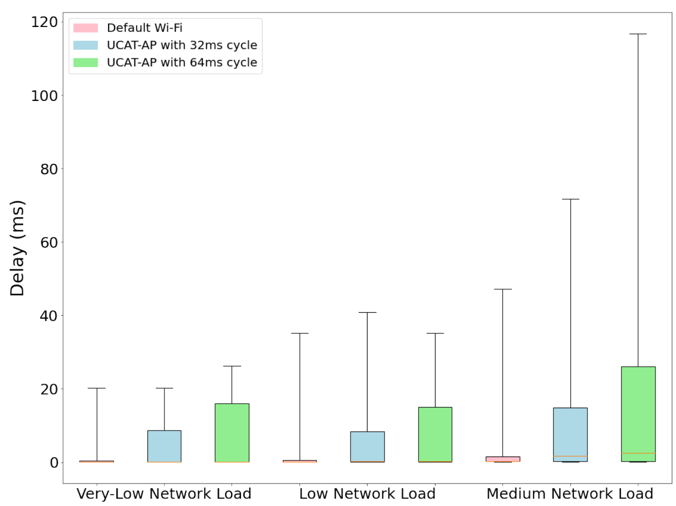


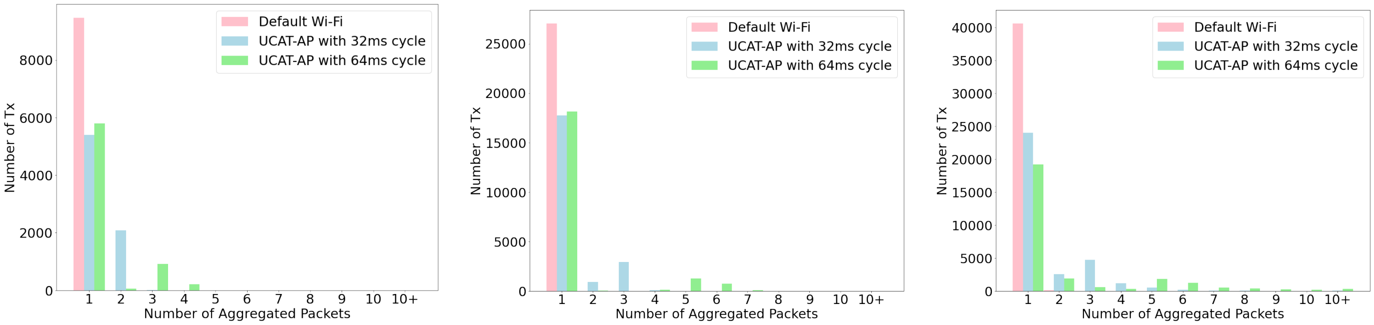
Fig. 3: Delay comparison graph

Figure 4 depicts the number of total transmissions in all scenarios with the number of aggregated packets. Figure 4a, 4b, and 4c give the total number of packets for very-low network load, low network load, and medium network load. It is seen that when no energy saving mechanism is applied (default WiFi), all packets are sent as single packets and there is no aggregation possibility, no matter the network load. When the UCAT method is applied, since AP will be in standby mode for a certain time, there will be some packets in the queues of the client nodes that can be aggregated. As such it is seen that for very-low network load, there are aggregations of up to 4 packets for a communication cycle of 64 ms. For low-medium network load the number of aggregated packets increases, with some aggregated packets having up to 6 packets for 64 ms communication cycle and up to 4 packets for 32 ms communication cycle. With increasing network load to medium (Figure 4c) there will be even aggregated packets with more than 10 packets for a 64 ms communication cycle scenario. It is seen that the air-time utilization method for power saving in AP will increase the opportunity for packet aggregation, which in return will decrease the contention in the channel. The higher number of packets aggregated will mean lower channel access events in the network, boosting up the network throughput.

Figure 5 represents potential energy savings. According to the equation 3, energy savings are directly proportional to energy reduction in standby mode and idle time. When circumstances permit, it is possible to save up to 90% on energy consumption.

To see the effects of the proposed method in commercial devices, we gathered data sheets of commercial Wi-Fi modules to create Table II. It shows Tx, Rx, standby time energy consumption, and the energy reduction in the standby mode of Wi-Fi modules. In the case of WPEQ-405AX Wi-Fi module, we determined an average value for standby energy consumption as it is not stated in its datasheet. The standby energy reduction percentage is calculated according to the case where the APs are in Rx mode. As a result, those values are the minimum energy reduction value for given Wi-Fi modules. All the Wi-Fi modules except WPEQ-405AX are low-power Wi-Fi modules. Thus they use less energy compared to newer ones which are designed for the latest technology such as 802.11ax.

Figure 6 represents potential energy saving in commercial devices with a 10% standby time increment. As the energy saving depends on the energy reduction and standby percentage, results vary in a range from ∼5% to ∼90%. Most of the given devices have more than 70% energy reduction in standby mode. This leads to, with a 0.5 fraction of time to switch standby mode, from 30% to 50% power saving can be



(a) Very-Low load scenario

(b) Low load scenario

(c) Medium load scenario

Fig. 4: Comparison of the number of transmissions and aggregated packets

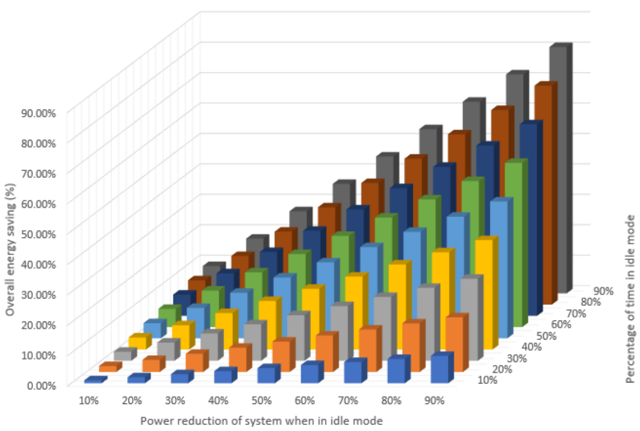


Fig. 5: Potential energy saving percentage for an AP

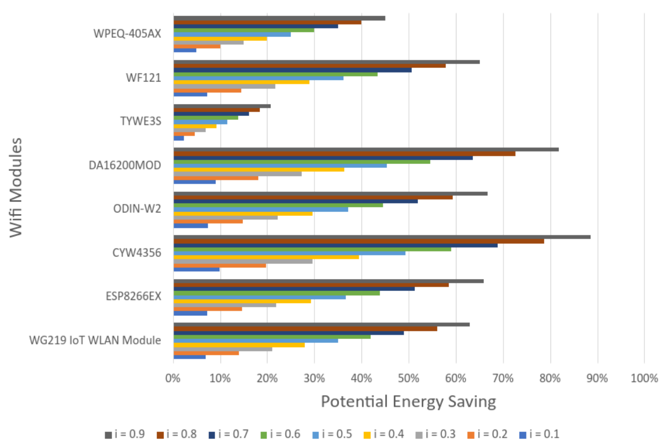


Fig. 6: Potential energy savings for commercial Wi-Fi modules

achieved.

V. Conclusion & Future Work

In this paper, we proposed a new approach to reducing APs' energy usage. Our key objective is to save energy while maintaining AP functionality and staying under the latency bound. To save energy, the UCAT takes advantage of unused airtime to switch Wi-Fi module to standby mode. Thus, continued connectivity is enabled while APs conserve energy. To determine the impact of the standby time frame duration, we evaluated the suggested method with two distinct communication cycles, i.e. 32 ms and 64 ms, with AP being on standby mode 25% of the time. The results indicate that when compared to 64 ms cycle tests, 32 ms cycle tests perform better in terms of average latency. At last, potential energy savings are calculated. According to such calculations, an AP's energy savings can reach up to 90% in very-low load networks while standby state energy savings for APs are about 90%.

In future work, to extend the proposed method, a cross-layer approach can be created using latency requirements information taken from the application layer. With the information gathered, APs can calculate their schedule and notify nodes about their standby period. Additionally, Proof of Concept (PoC) is always a good choice to see the real-time effects of the proposed work. Results gathered from PoC can be compared to the values found in this work.

Acknowledgment

This work was supported by the CHIST-ERA grant SAMBAS (CHIST-ERA-20-SICT-003), with funding from FWO, ANR, NKFIH, and UKRI.

References

[1] Giorgos Fagas et al. "Energy challenges for ICT". In: *ICT-Energy Concepts for Energy Efficiency and Sustainability*. IntechOpen Rijeka, Croatia, 2017, pp. 1–36.

[2] *Cisco Annual Internet Report (2018–2023) White Paper*. Accessed: Dec 2022. URL: https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html.

[3] *ABI Research anticipates in-building mobile data traffic to grow by more than 600% by 2020*. Accessed: Dec 2022. URL: https://www.abiresearch.com/press/abi-research-anticipates-building-mobile-data-traf/.

[4] Paulo Silva, Nuno T Almeida, and Rui Campos. "A comprehensive study on enterprise Wi-Fi access points power consumption". In: *IEEE Access* 7 (2019), pp. 96841–96867.

TABLE II: Energy consumption of Wi-Fi modules

Wi-Fi Module Name	Active Tx Current	Active Rx Current	Standby Energy Consumption	Standby Energy Reduction
WPEQ-405AX [18]	1954 mA	819 mA	410* mA	0.5
WF121 [19]	143 mA	127 mA	35 mA	0.72
TYWE3S [20]	100 mA	76 mA	58.5 mA	0.23
DA16200MOD [21]	200 mA	38.5 mA	3.5 mA	0.91
ODIN-W2 [22]	220 mA	140 mA	36 mA	0.74
CYW4356 [23]	340 mA	140 mA	2 mA	0.99
ESP8266EX [24]	120 mA	56 mA	15 mA	0.73
WG219 IoT WLAN Module [25]	120-180 mA	50-60 mA	15 mA	0.70

[5] Łukasz Budzisz et al. "Dynamic resource provisioning for energy efficiency in wireless access networks: A survey and an outlook". In: *IEEE Communications Surveys & Tutorials* 16.4 (2014), pp. 2259–2285.

[6] Markus Tauber and Saleem N Bhatti. "The effect of the 802.11 power save mechanism (PSM) on energy efficiency and performance during system activity". In: *2012 IEEE International Conference on Green Computing and Communications*. IEEE. 2012, pp. 573–580.

[7] Jetmir Haxhibeqiri et al. "A survey of LoRaWAN for IoT: From technology to application". In: *Sensors* 18.11 (2018), p. 3995.

[8] Paulo Silva, Nuno T Almeida, and Rui Campos. "Energy consumption management for dense Wi-Fi networks". In: *2019 Wireless Days (WD)*. IEEE. 2019, pp. 1–8.

[9] *IEEE Time-Sensitive Networking (TSN) Task Group*. URL: http://www.ieee802.org/1/tsn.

[10] Jetmir Haxhibeqiri et al. "Bringing Time-Sensitive Networking to Wireless Professional Private Networks". In: *Wireless Personal Communications* 121.2 (2021), pp. 1255–1271.

[11] Jingjin Wu et al. "Energy-efficient base-stations sleep-mode techniques in green cellular networks: A survey". In: *IEEE communications surveys & tutorials* 17.2 (2015), pp. 803–826.

[12] Priyangshu Ghosh et al. "Energy saving in OFDMA cellular systems using base-station sleep mode: 3GPP-LTE a case study". In: *2012 National conference on communications (NCC)*. IEEE. 2012, pp. 1–5.

[13] Konstantinos Samdanis, Dirk Kutscher, and Marcus Brunner. "Self-organized energy efficient cellular networks". In: *21st Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*. IEEE. 2010, pp. 1665–1670.

[14] Ahmad M Kholaif et al. "QoS-enabled power saving access points for IEEE 802.11 e networks". In: *2008 IEEE Wireless Communications and Networking Conference*. IEEE. 2008, pp. 2331–2336.

[15] Masakatsu Ogawa. "Cross-layer queuing control in mobile router for power saving". In: *2013 9th International Wireless Communications and Mobile Computing Conference (IWCMC)*. IEEE. 2013, pp. 849–854.

[16] *Cisco Catalyst 9800 Series Wireless Controller Software Configuration Guide*. Accessed: Dec 2022. URL: https://www.cisco.com/c/en/us/td/docs/wireless/controller/9800/config-guide/b_wl_16_10_cg/overview-of-controller.html.

[17] *Green AP*. Accessed: Dec 2022. URL: https://www.arubanetworks.com/techdocs/ArubaOS_87_Web_Help/Content/arubaos-solutions/access-points/gren-ap.htm?Highlight=green+AP.

[18] *WPEQ-405AX - Qcn9074 MU-MIMO WIFI-6 module 4x4*. Accessed: Dec 2022. URL: https://www.sparklan.com/product/qcn9074-mu-mimo-wifi6-module-4x4/.

[19] *WF121 Wi-Fi MODULE DATA SHEET*. Accessed: Dec 2022. URL: https://www.silabs.com/documents/public/data-sheets/WF121-DataSheet.pdf.

[20] *Tywe3s module Datasheet*. Accessed: Dec 2022. URL: https://developer.tuya.com/en/docs/iot/wifie3smodule?id=K9605ua1cx9tv#title-11-Working%5C%20power%5C%20consumption.

[21] *Ultra Low Power WIFI Soc*. Accessed: Dec 2022. URL: https://www.renesas.com/us/en/document/dst/da16200mod-datasheet.

[22] *ODIN-W2 series data sheet*. Accessed: Dec 2022. URL: https://content.u-blox.com/sites/default/files/ODIN-W2_DataSheet_UBX-14039949.pdf.

[23] *Single-Chip 5G WiFi IEEE 802.11ac 2×2 MAC/Baseband/Radio with Integrated Bluetooth 5.0*. Accessed: Dec 2022. URL: https://www.infineon.com/dgdl/Infineon-CYW4356_CG8674_Single-Chip_5G_WiFi_IEEE_802.11ac_2x2_MAC_Baseband_Radio_with_Integrated_Bluetooth_5.0-AdditionalTechnicalInformation-v03_00-EN.pdf?fileId=8ac78c8c7d0d8da4017d0ee4c6ad6bfa.

[24] *esp8266ex datasheet*. Accessed: Dec 2022. URL: https://www.espressif.com/sites/default/files/documentation/0a-esp8266ex_datasheet_en.pdf.

[25] *wg219 iot wlan module datasheet*. Accessed: Dec 2022. URL: http://www.skylab.com.cn/uploads/admin/202202/62189d7df059b.pdf.