Modeling Energy Aspects of ASIC Hardware for PoW Applications

B. Bijelić*, M. Hercog*, G. Horvat*, I. Ostheimer*, M. Vukobratović*
* Base58 Ltd., Systems Engineering Department, Osijek, Croatia

Abstract—**Blockchain validation hardware requires considerable amount of energy to perform computational operations for its main purpose. Computational performance is equally important as energy consumption for profitable operation. Goal of this paper is to experimentally determine electrical and computational values and compare them with data provided by the manufacturer. First, theoretical model is defined. It describes electrical and computational values which are observed in this research and provides context to the reader why this metrics are important. Furthermore, laboratory environment in which experiment is done and methodology are explained. To answer question whether manufacturer data is to be trusted, three different models of ASIC hardware are put under test. Extensive tests determined that experminetally obtained data is in accordance with manufacturer provided data.**

***Keywords*—ASIC hardware, blockchain, efficiency, energy, hash-rate, PoW**

I. INTRODUCTION

An application-specific integrated circuit (ASIC) hardware implies integrated circuit chip that has been designed and manufactured for a single purpose. ASICs are highly specialized and powerful computers that made a significant change in the world of cryptocurrencies, such as cryptocurrency bitcoin, when they emerged in 2013 and since then its efficiency has been constantly increasing [1]. Without that type of hardware, today's Bitcoin network wouldn't be as solid and resilient, but running many devices is an energy-intensive endeavour. There have been significant attempts to describe multiple impacts of mass-deployed ASIC hardware. Majority of research observes overall energy consumption and provide a contextual comparison with energy consumption of national economies [2] [3] [4] or national usages of such infrastructure in regulated environment [5], where the University of Cambridge [1] provides their estimated data of energy consumption almost in real time. According to their research, the primary blockchain based on the SHA-256 algorithm, that of the cryptocurrency bitcoin, consumes electricity comparable to the countries of Norway and Poland. It is also interesting to mention that the wealth currently created in the Bitcoin eco-system per TWh is almost twice as high as GDP in Norway, and 20% to 30% higher than GDP in Poland, which indicates the bespoke efficiency of converting energy into stored value [6].

With the changes in the electricity market during 2021, it is interesting to observe how the applications of specialized SHA-256 ASIC hardware and the electricity market are related [7] and whether it is worthwhile to continue to use the observed ASIC for a specific economic purpose in the context of rising electricity prices [8]. Also, one interesting thing is to observe the possibilities to make the volatility of certain renewable energy sources more stable using the ASIC hardware specialized for the Bitcoin ecosystem [9].

The biggest challenge for such mass application is how to guarantee hardware performance and how to know whether to recognize whether ASIC hardware is performing its primary and single function properly. Given the fast-growing and highly competitive market and the financial incentives for rapid hardware deployment, equipment manufacturers can in some cases declare performance that is unattainable in nature, all to win over customers. If taken into account that more and more industrial purposes for this type of ASIC hardware in the context of the power market are being considered, it becomes clear how crucial it is to know what has been dealt with. Mass industrial and standardized application of ASIC hardware in the context of electricity market and volatile renewable generation management can only be achieved if the performance of ASIC hardware is well familiar and the irregularities can be identified from the usual industrial measurements. This paper analyses the performance of most widely used ASIC hardware, without observing GPU and CPU performance since ASIC hardware is predominantly used today. The conversion of electricity into value takes place in a so-called mining process based on the hash-rate metric, described later in the paper. Briefly, hash-rate is a discrete metric and is related to the computing power of an ASIC device, while the number of combinations created with a specific hash-rate is expressed in the number of hashes in time, just as power in time is expressed as energy. The goodness of the ASIC hardware observed in this paper is expressed as the ratio of the electricity consumed and the hash-rate that the hardware provided for that consumption.

To utilize mass-produced ASIC hardware, used for blockchain validation, in industrial and standardized environments, it is necessary to understand the behaviour of hardware through multiple aspects such as: relationship between power consumption and computing work performed, performance stability over time; and the relationship between declared and actual data. Complete and clear idea of ASIC hardware performance makes possible the creation of hybrid technical and technological solutions based on this type of hardware.

The paper is organized as follows: Section 2 provides key information for understanding the efficiency of converting electricity into value through the computer work of making hash records. This chapter clearly shows the mathematical models that describe ASIC hardware and its primary purpose in the Bitcoin ecosystem; Section 3 describes the laboratory environment and test protocol, work methodology and observed values; Section 4 provides results and critical analysis of results and comparison with nominal data; Section 5 gives a conclusion and an end view of the whole paper.

II. Theoretical Model

In this section, electrical and computational metrics of observed ASIC hardware are defined. To form mathematical framework described in Section 3 of this paper, following metrics are defined: the correlation between Joules and energy and hash-rate metric with explained efficiency of ASIC hardware. Brief overview of high-level ASIC components is also presented.

A. Energy

Energy is the basis of the development of life, the basic human need and the foundation for the development of modern society. Energy cannot be created or destroyed but can only be changed from one form to another. In every energy transformation, some amount is always lost in the form of heat [10]. Lately, humanity has been looking for ways to convert the limited available energy as efficiently as possible into a value that can raise the quality of life. An unknown author under the pseudonym Satoshi Nakamoto presented to the world 13 years ago a technology that today has proven to be the most efficient for converting electricity into a transferable form of value - cryptocuurency based on energy called bitcoin [11]. From that moment on, the use of electricity is viewed differently in order to achieve financial benefits.

It is generally known that Energy is expressed in Joules which is defined as:

$$J = Ws = Wh \cdot 3600 \tag{1}$$

Efficiency of ASIC hardware is the only feature that distinguishes the world's leading manufacturers in a dynamic and competitive market.

To compare efficiency of ASIC hardware, energy consumption is represented in *Joules* per fitness of computing performance, called hash-rate [12]. *Joule* represents amount of work required to produce one Watt for one second and is presented by Equation 1.

To perform steady-state analysis, average 15 minute energy consumption is calculated from 15 minute interval measurements via following Equation 2:

$$E_{avg} = \frac{4}{N} \sum_{i=1}^{N} E_i \qquad \text{[Wh]} \tag{2}$$

where E_i is 15 minute interval energy measurement expressed in watt-hours, and N is total number of measurements. Average 15 minute energy consumption is then multiplied by 4 to obtain average full hour energy consumption.

B. Hash-rate Metric

To properly understand hash-rate, hashing as a cryptographic function should be observed first. Hashing is a cryptographic process of producing fixed length output from given input content. Different hashing algorithms produce output, sometimes called *digest*, of different lengths. Hashing algorithms are *one-way* functions, meaning there is no way of retreiveing input from output. Number of hashing operations which can be performed in a unit of time is defined by metric *hash-rate* [12]:

$$HR = \frac{H}{\Delta t} \qquad \text{[TH/s]} \tag{3}$$

where H represents total count of hash operations and Δt time interval.

To perform steady-state analysis, average value is calculated via Equation 4:

$$HR_{avg} = \frac{1}{N} \sum_{i=1}^{N} H_i \qquad \text{[TH/s]} \tag{4}$$

Nominal power efficency η is provided by the manufacturer for a given ASIC model at a given ambient temperature of $25°C$.

C. ASIC Efficiency

Efficiency is defined as ratio of energy consumed, expressed in Joules and hash-rate performed by the device in the same time period. Relation between watt-hours and joules is described by Equation 1. Average efficiency is described by Equation 5:

$$\eta_{avg} = \frac{E_{avg} \cdot 3600}{HR_{avg} \cdot 3600} \qquad \text{[J/TH]} \tag{5}$$

where average energy consumption E_{avg} is multiplied by a number of seconds within hour to obtain watt-seconds, and average hash-rate metric HR_{avg} is multiplied by a number of seconds within hour to obtain total amount of hash operations within single hour.

D. ASIC Components Overview

In this subsection, we observe most common high-level components of an ASIC device: power supply unit, control board, hashing board and cooling fans.

a) Power Supply Unit: Supplies control board and one or multiple hashing boards with needed power.

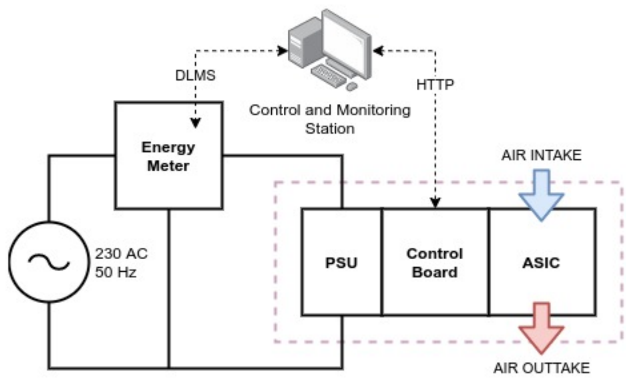

Fig. 1: Schema of laboratory environment

b) Control Board: Provides network interface for the ASIC hardware and acts as controller for the ASIC integrated circuits on hashing boards. Control board is also responsible to monitor temperature of the hardware and control cooling fans so that device can operate within designed limits.

c) Hashing Board: ASIC device is composed of one or more hashing boards. Single hashing board contains tens or hundreds of integrated circuit chips which perform cryptographic functions.

d) Cooling Fans: ASIC device consumes respectable amount of energy and significant proportion of consumed energy is dissipated through heat. High-speed controllable fans are required to bring the temperature to acceptable limits.

III. Laboratory Environment

Laboratory environment is designed to measure physical and computational metrics of an ASIC hardware under test. ASIC hardware is observed by steady-state analysis and comparison of empirical and nominal data. Environment is composed of multiple components: Control and monitoring station equiped with software for data extraction from smart meter device, Iskraemeco ME382 smart meter device equiped with optical probe interface and ASIC hardware under test. Figure 1 describes laboratory environemnt, while ASIC hardware under test is outlined in table I.

As outlined in section 1, measurements are conducted for each ASIC device under test independently. Measurements are collected at 15 minute resolution over 5 hours and are correlated by sample time.

Energy consumption is sampled by smart meter device and data is collected by Device Language Message Specification (DLMS) protocol via control and monitoring station. DLMS protocol is industry standard protocol for smart meters.

Control and monitoring station is installed with open source software - Gurux DLMS Director which is used to collect sampled data from smart meter device. Smart meter device is connected to control and monitoring station via Iskraemeco Sonda 5 optical probe interface.

TABLE I: Manufacturer provided data

Bitmain Antminer S9j	
Hash-rate [TH/s] $\pm\sigma$	$14.5 \pm 5\%$
Energy [Wh] $\pm\sigma$	$1350 \pm 10\%$
Efficiency [J/TH] $\pm\sigma$	$93.12 \pm 10\%$
Bitmain Antminer S19 Pro	
Hash-rate [TH/s] $\pm\sigma$	$110 \pm 3\%$
Energy [Wh] $\pm\sigma$	$3250 \pm 5\%$
Efficiency [J/TH] $\pm\sigma$	$29.5 \pm 5\%$
MicroBT Whatsminer M30S+	
Hash-rate [TH/s] $\pm\sigma$	$100 \pm 5\%$
Energy [Wh] $\pm\sigma$	$3400 \pm 10\%$
Efficiency [J/TH] $\pm\sigma$	$34 \pm 5\%$

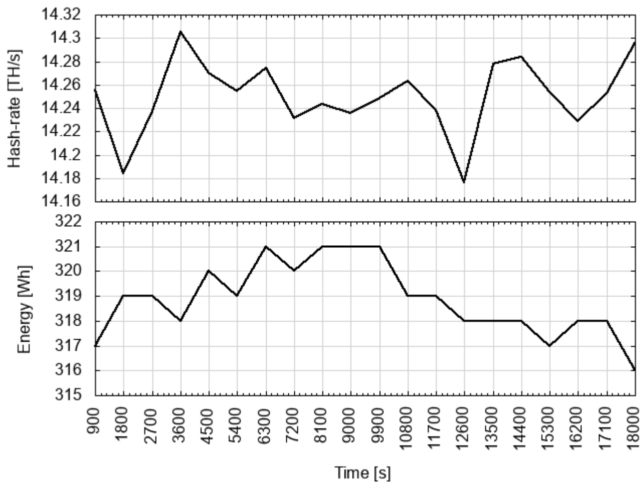

Fig. 2: Bitmain Antminer S9j experimental data

Hash-rate of ASIC device is collected via HTTP interface provided by ASIC hardware. ASIC hardware is installed with manufacturer stock firmware and no modifications are done which may impact observed values in any form.

Average energy consumed over one hour by ASIC device is calculated from measured 15-minute samples via Equation 2. Similarly, average hash-rate of the ASIC device is calculated from measured 15-minute samples and expressed in tera-hash-per-second via Equation 4. Finally, average efficiency is calculated by using Equation 5.

IV. Results and Discussion

In this section we present and discuss results of the laboratory testing. Results are obtained by following methodology described in section 2. For each ASIC device, measured average values for energy consumption, hash-rate and efficiency are presented. Overview of experminetal data is presented in Table II.

a) Bitmain Antminer S9j: Experimentally determined average energy consumption of 1275.4 Wh, hash-rate of 14.25 TH/s and derived efficiency of 89.5 J/TH by using Equation 5 are within manufacturer provided data ranges.

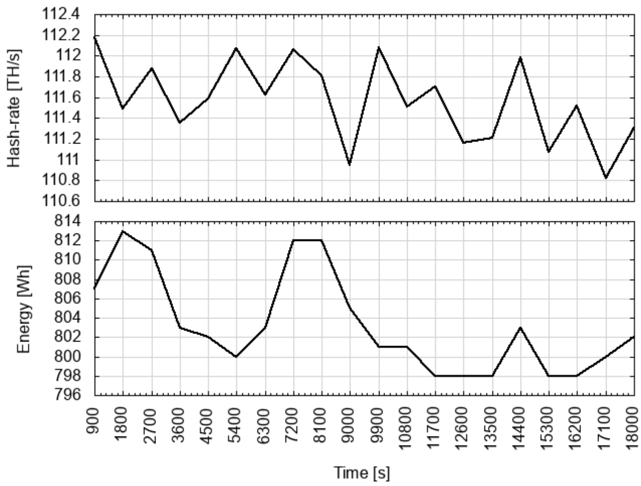

Fig. 3: Bitmain Antminer S19 Pro experimental data

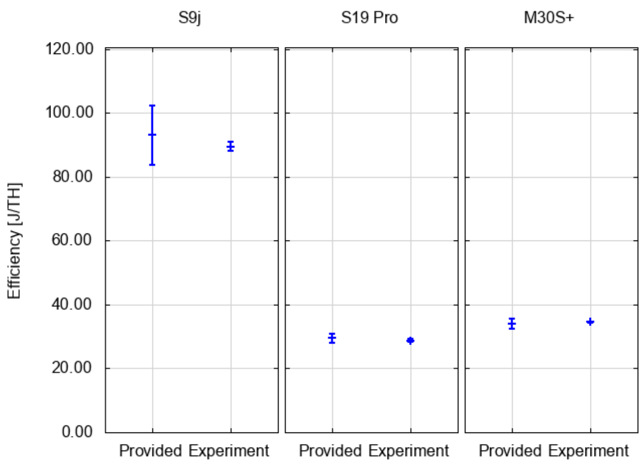

Fig. 5: Efficiency Comparison

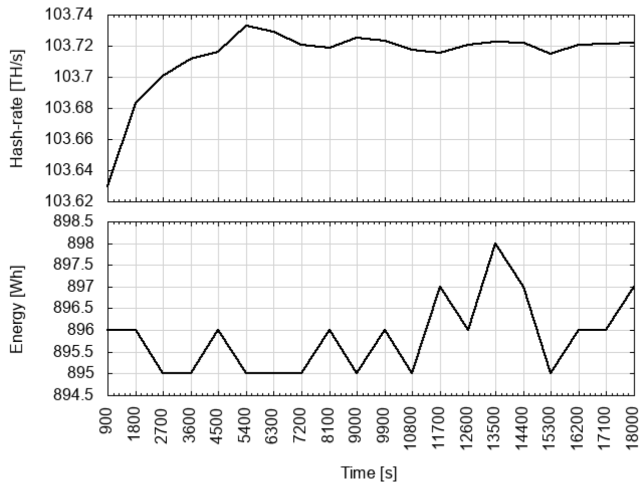

Fig. 4: MicroBT Whatsminer M30S+ experimental data

TABLE II: Experimental data

Bitmain Antminer S9j	
Hash-rate [TH/s] $\pm\sigma$	$14.25 \pm 0.67\%$
Energy [Wh] $\pm\sigma$	$1275.4 \pm 1.27\%$
Efficiency [J/TH] $\pm\sigma$	$89.5 \pm 1.64\%$
Bitmain Antminer S19 Pro	
Hash-rate [TH/s] $\pm\sigma$	$111.57 \pm 1.08\%$
Energy [Wh] $\pm\sigma$	$3213 \pm 1.46\%$
Efficiency [J/TH] $\pm\sigma$	$28.8 \pm 1.79\%$
MicroBT Whatsminer M30S+	
Hash-rate [TH/s] $\pm\sigma$	$103.71 \pm 0.06\%$
Energy [Wh] $\pm\sigma$	$3583.4 \pm 0.23\%$
Efficiency [J/TH] $\pm\sigma$	$34.55 \pm 0.3\%$

Experimentally determined data of *Bitmain's Antminer S9j* are shown in Figure 2.

b) Bitmain Antminer S19 Pro: Experimentally determined average energy consumption of 3213 Wh, hash-rate of 111.57 TH/s and derived efficiency of 28.8 J/TH by using Equation 5 are within manufacturer provided data ranges. Experimentally determined values of *Bitmain's Antminer S19 Pro* are shown in Figure 3.

c) MicroBT Whatsminer M30S+: Experimental determined energy consumption of 3583.4 Wh, hash-rate of 103.71 TH/s and derived efficiency of 34.55 J/TH by using Equation 5 are within manufacturer provided data ranges. Experimentally determined values of *MicroBT's Whatsminer M30S+* are shown in Figure 4.

A. Discussion

Experimental data clearly shows how observed values - power consumption, hash-rate and efficiency - are within manufacturer defined ranges. The most inefficient ASIC device of three observed is *Antminer S9j*. Released in August 2018, *Antminer S9j* is oldest of observed ASIC devices and at the moment of writing this paper it is considered to be unprofitable to run, considering energy prices on the power market, exchange rate of cryptocurrency Bitcoin, and overall global computational power expressed as global hash-rate. Profitability is calculated by subtracting the operation cost from the total mining revenue. Mining revenue is a dynamic value conditioned by the above mentioned parameters of the Bitcoin network. Aforementioned, operation cost is the sum of all expenses involved in this operation, of which most dominant is the price of electiricy. Efficiency comparison of provided and experimental data is shown in Figure 5.

Following, *Whatsminer M30S+* Released in October 2020, *Whatsminer M30S+* is one of the most efficient ASIC devices on the market. Laboratory testing indicates efficiency of *Whatsminer M30S+* to be in similar range of *Antminer S19 Pro*, however, lower.

Released in May 2020, *Antminer S19 Pro* is the most efficient device of all three devices observed. At the moment of writing this paper, it is considered to be one of most efficient ASIC devices on the market.

Empirical testing in laboratory conditions has proven that today's generations of ASIC hardware can be reliably used in industrial applications since the nominal data correspond to the data obtained by testing. Such tests are necessary to understand the behavior of ASIC hardware in industrial and institutional settings, and the *a posteriori* approach allows for subsequent analysis and in-depth testing in cases of additional validation.

V. Conclusion

Understanding the behavior and efficiency of ASIC hardware used for blockchain validation is the key for its successful implementation in industrial environment. Although, manufacturers of ASIC hardware declare nominal values for power consumption, efficiency and hash-rate, the goal of this paper is to observe, measure and compare these values with manufacturer data through stable laboratory environment and proven methodology.

By observing power consumption, hash-rate and efficiency of three different ASIC hardware models, experiment proved how values obtained by laboratory testing are within range limits defined by a manufacturer of the hardware. Experiment did not determine any deviations while comparing data.

Significance of results presented in this paper is contained in data validity and industrial potential. Mass deployment of ASIC hardware for blockchain validation in industrial environments is the paradigm of second decade of this technology. Trust in data provided by manufacturer is key to precisely estimate energy consumption, mitigate financial losses and prevent technical issues on large scale.

Future research could consider applying experiments described in this paper on a larger scale, i.e. measuring physical and computational valuess on a group of ASIC devices in industrial environment. For such expansion, first a large-scale investments need to start. Although, this paper focused on energy aspects of AISC hardware models and presented poor efficiency of older ASIC hardware like Antminer S9j, future research could provide framework for profitability calculation in regard to power efficiency and state of cryptocurrency markets.

VI. Acknowledgments

This research was co-funded by project "SIMBA", through the grant of Ministry of Economy and Sustainable Development "Integrator/KK.03.2.2.05" of the program "Competitiveness and Cohesion 2014–2020" from the European Regional Development Fund.

References

[1] University of Cambridge, "Cambridge Bitcoin Electricity Consumption Index." [Online]. Available: https://ccaf.io/cbeci/index

[2] A. Beall, "Bitcoin energy bill matches Ecuador's," *New Scientist*, vol. 236, no. 3150, p. 8, 2017. [Online]. Available: http://dx.doi.org/10.1016/S0262-4079(17)32143-7

[3] A. de Vries, "Bitcoin's energy consumption is underestimated: A market dynamics approach," *Energy Research and Social Science*, vol. 70, no. February, p. 101721, 2020. [Online]. Available: https://doi.org/10.1016/j.erss.2020.101721

[4] S. Küfeoğlu and M. Özkuran, "Bitcoin mining: A global review of energy and power demand," *Energy Research and Social Science*, vol. 58, no. June, p. 101273, 2019. [Online]. Available: https://doi.org/10.1016/j.erss.2019.101273

[5] C. E. Clark and H. Greenley, "Bitcoin, Blockchain, and the Energy Sector," Congressional Research Service, Tech. Rep., 2019.

[6] Statista, "Market capitalization of Bitcoin from April 2013 to February 2, 2022." [Online]. Available: https://www.statista.com/statistics/377382/bitcoin-market-capitalization/

[7] S. Corbet, B. Lucey, and L. Yarovaya, "Bitcoin-energy markets interrelationships - New evidence," *Resources Policy*, vol. 70, p. 101916, mar 2021. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0301420720309478

[8] A. de Vries, "Bitcoin boom: What rising prices mean for the network's energy consumption," *Joule*, vol. 5, no. 3, pp. 509–513, mar 2021. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S2542435121000830

[9] C. L. Bastian-Pinto, F. V. d. S. Araujo, L. E. Brandão, and L. L. Gomes, "Hedging renewable energy investments with Bitcoin mining," *Renewable and Sustainable Energy Reviews*, vol. 138, p. 110520, mar 2021. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S1364032120308054

[10] National Institute of Open Schooling, "Importance of energy in society," pp. 83–95, 2019. [Online]. Available: https://nios.ac.in/media/documents/333courseE/27B.pdf%0Ahttps://www.youtube.com/watch?v=ku4cfZBs4Jg

[11] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2009. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[12] N. D. Bhaskar and D. L. K. Chuen, "Bitcoin Mining Technology," in *Handbook of Digital Currency*. Elsevier, 2015, pp. 45–65. [Online]. Available: http://dx.doi.org/10.1016/B978-0-12-802117-0.00003-5https://linkinghub.elsevier.com/retrieve/pii/B9780128021170000035