ENERGY EFFICIENT BITCOIN MINING TO MAXIMIZE THE MINING PROFIT: USING DATA FROM 119 BITCOIN MINING HARDWARE SETUPS

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Abstract - In recent years, cryptocurrency such as Bitcoin has attracted much global attention. Bitcoins are produced by mining as a fee for authenticating any transaction. This process requires a significant amount of computing power. In the early stage, mining started from personal computers and currently, specialized hardware developed to increase the mining speed by reducing power consumption. Therefore, this research aims to explore the impact of hardware efficiency from the early stages of Bitcoin mining hardware to current customized mining hardware for better Bitcoin mining process to maximize mining profit. In this study, we analyzed miner performance from basic to advance hardware and discuss how to identify a suitable miner to increase the profit by comparing their performance and price. We extracted data from 30 peer-reviewed scientific publications (2013–2018) describing 119 Bitcoin mining hardware setups to record the power consumption and hash rates for cryptocurrency mining. Hardware efficiencies were calculated using power consumption and hash rate, then compared with different miners for identification purposes. Our findings suggest that Nvidia GPUs are inefficient and more expensive than the ATI GPUs. Additionally, ASICs and FPGA miners are more efficient compared to CPU and GPU miners. The BitmainAntminer S9 is the most efficient miner for cryptocurrency mining. This study could be utilized to identify common hardware efficiencies to maximize Bitcoin mining profits. Moving to cloud/hosting solutions rather than spending money on upgrading mining hardware could be an exciting future research avenue.

Keywords - Cryptocurrency, Bitcoin, Mining, Efficiency, Hash rates, Hardware.

Graphical Abstract

I. INTRODUCTION

Cryptocurrency is a decentralized digital currency designed using cryptography to work as an exchange medium over the internet due to the rapid growth of information technology. Bitcoin is the first implementation of cryptocurrency, which was introduced in late 2008 [1] by Satoshi Nakamoto. Since bitcoin deployment in 2009 [2], it has become the most successful digital currency despite there being around 900 [3] cryptocurrencies. Bitcoin can be acquired by "merchandising, providing services, exchanging with other currencies" [3] besides, mining is the practice used to harvest these virtual currencies.

As the first step of Bitcoin mining, users install free software, which is known as a wallet (free client) to their computers to send and receive money using Bitcoin addresses. Participants (miners) who are joined to the Bitcoin network broadcast blocks (A block is a container of Bitcoin transaction [4]) into the public blockchain using a secure hashing algorithm (SHA-256) [5] after verifying transactions into blocks. For each block, miners get rewarded with 25 new Bitcoins and every 10 minutes [1] a new block is generated by one of the miners in the Bitcoin network. As this mining process creates hashes of transactions, the miner keeps their block in a loop as fast as possible thus consuming a lot of "processor cycles" [4] and therefore a large amount of electricity.

Initially, mining started on standard computers. As it gained popularity, miners attempted to increase their hash rates [6] by using different hardware. As a result, Bitcoin protocols made mining more difficult [7] over time. The general public who used their computing resources such as 1st and 2nd generation Central Processing Unit (CPU) and Graphic Processing Unit (GPU) miners became out of date as their hardware failed to keep up with difficulty to gain a reasonable profit. Additionally, selecting a mining pool also became complicated due to the introduction of various pools to the cryptocurrency network, which requests specific hardware. Hence, conducting more comprehensive research will be essential to identify the appropriate parameters such as energy consumption, hash rates and hardware prices when choosing the right tools for Bitcoin mining.

A miner called "Andrew Geyls" [4] and researched studies pointed out how many people could be losing money while mining Bitcoin. According to Lee and Kim [8], the main reason is, miners, fail to continue to invest in hardware as the network increases the mining difficulty every two weeks. As a result, over time, the hardware generates fewer hashes and consumes more electricity. Therefore, many papers compare the electricity consumption price with the Bitcoin value as it is a way of trading energy without focusing on inexpensive, efficient hardware. An estimation of hardware energy consumption is essential [9-11], as it consumes energy in different ways.

Development of mining-specific Field-programmable Gate Arrays (FPGAs) and Application Specific Integrated Circuits (ASICs) has made the use of consumer CPUs and GPUs miners outdated [8]. Nonetheless, graphics cards (GPUs) can be used to develop customized ASIC miners to achieve higher hash rate and compete with other devices. Therefore, this paper used 119 hardware devices to extract experimental data from 30 studies to analyze their efficiency and expenses by comparing each device to maximize the Bitcoin mining profit.

II. MATERIAL & METHODS

2.1. Collection of raw data

Bitcoin mining hardware data was collected such as hash rates, power consumption, price, release dates and the efficiency of different hardware types such as central processing unit (CPU), graphics processing unit (GPU), application-specific integrated circuits (ASIC) and field-programmable gate arrays (FPGA). The individual data for these elements is shown in Table 1 and Table S1. This investigation contains 30 studies that used 119 different hardware types for Bitcoin mining.

Device type	The core elements of a computer. Ex. CPU, GPU.
Hardware	The collection of physical parts of a computer system.
Power consumption	The electricity power used by a device.
Hash rate	The speed at which a computer is completing an operation in the Bitcoin code.
Efficiency	Ability to perform a task with minimum wastage.
ASIC	Application-specific integrated circuit.
FPGA	Field-programmable gate array.

Table 1: Parameters used in raw data collection (Table S1)

Since some authors [2, 5, 9] did not mention the efficiency of the hardware while measuring the hash rates and the power consumption, we calculated the efficiency using equation (1). However, it should be noted that a few authors [4, 6,] have calculated the efficiency by dividing the Hash rate by Power consumption.

2.2. Data Processing

In our survey, power consumption data was recorded in watts (W) and hash rates in Giga hashes per second (Gh/s). Since few studies used different units to analyze the hash rates, we used Giga hash value (1Gh/s = 1000Mh/s) as shown in Table S1.

2.3. Efficiency Calculation

Attributes such as electricity cost and performance per dollar are not crucial for this evaluation since efficiency is the most essential element. Some authors [7, 10] calculated the efficiency of Bitcoin mining using W/Gh/s and equation 1.

That is, the mining efficiency attribute was calculated using power consumption and hash rates that are given by [6]. As such, the lowest value indicates the most efficient hardware:

$$\text{mining efficiency} = \frac{\text{power consumption (W)}}{\text{hash rate (Gh/s)}} \quad (1)$$

2.4. Data Analysis

Hardware specifications data presented in Table S1 was mainly analyzed according to their individual performance and prices. Due to the publication period and operating conditions, studies indicated differentprices and hash rates for the same hardware. Parameters such as release date and price data are not mentioned in every study. Therefore, those data were extracted from the manufacturer's website or referenced web pages.

III. RESULTS

The main goal of this research is to identify the most efficient hardware device for Bitcoin mining without spending large amounts of money. To simplify the process, raw data were categorized according to device types. Subsequently, the data were branded accordingly for identification purposes. Four criteria were developed using the analyzed data to identify appropriate mining hardware. Figure 1 demonstrates the different processors' data discussed in the 30 studies. Specifically, Fig. 1(a) shows Intel processors, Fig. 1(b) shows Advanced Micro Devices (AMD) processors and Fig. 1(c) compares the two. Intel's price comparison indicates a slight increase in the middle while the AMD Fig. 1(b) has a consistent price. Similarly, in terms of efficiency, Intel slightly increases in the middle and AMD is steady. Fig. 1(c) confirms that AMD processors are more expensive than Intel's as the price comparison has a sudden peak in the middle. The efficiency comparison in Fig. 1(a), fluctuates from start to end.Therefore, Intel processors such as Atom N450, i7 990x, i7 2760QM, i7 3930k, and Xeon Phi 5100 can be identified as more efficient processors. According to Fig. 1(c), AMD processors are not efficient because they consume more power compared to the Intel series. Furthermore, Xeon Phi 5100 is more suitable than the rest, as it is inexpensive and consumes a reasonable amount of power to generate additional hashes. Therefore, AMD processors and rest of the Intel processors could not be identified as efficient mining hardware.

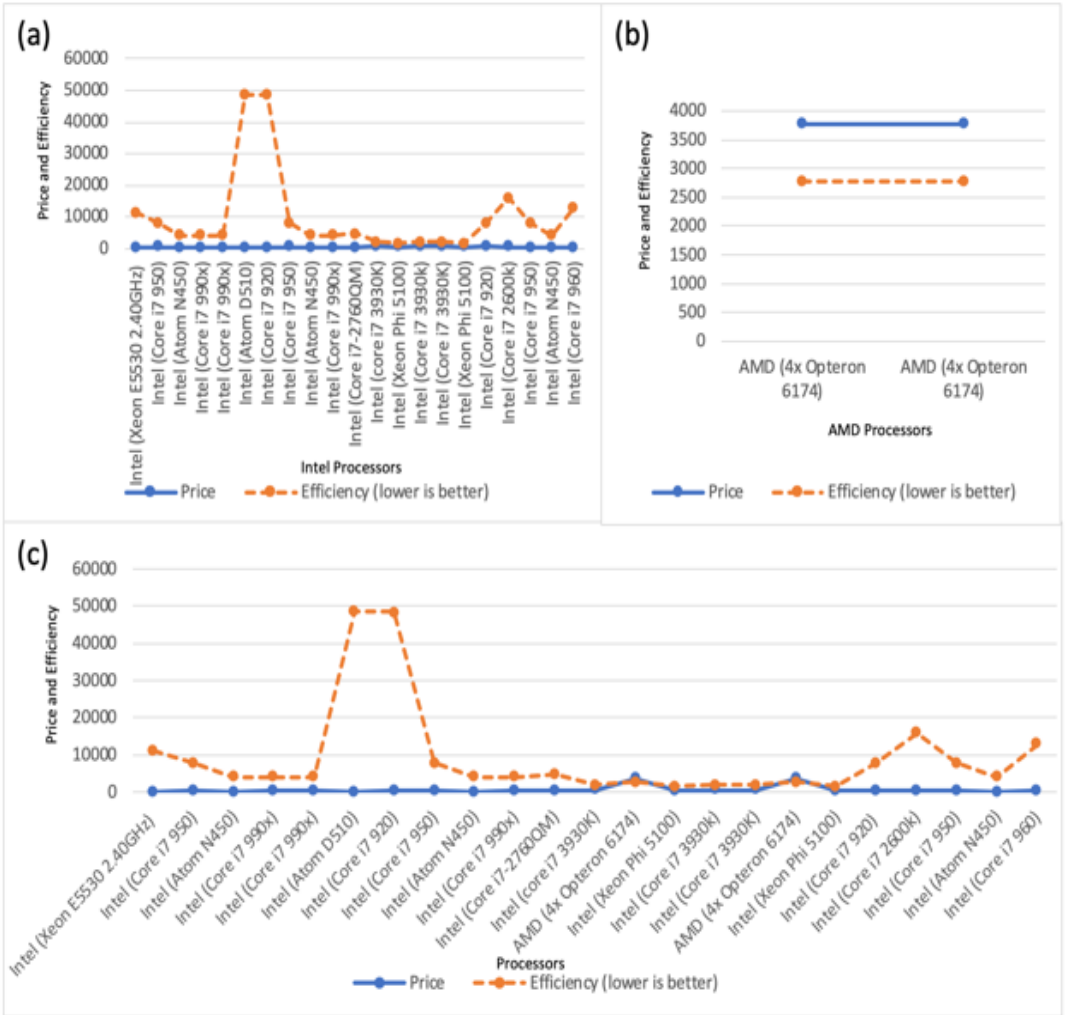

Fig.1. AMD and Intel manufacturer's processors (first generation miners) were compared to their prices and to their efficiencies. (a) for Intel, (b) for AMD and (c) for both Intel and AMD. 30 Bitcoin mining studies (from 2013 to 2018) were used to identify the efficiency and the price values. Since few papers provided power consumption and hash rate values, processor efficiency is calculated using the given equation. Efficiency = Power consumption(W) / Hash rate (Gh/s). Please note that price values are in solid blue lines and efficiency values are in orange dotted lines.

Graphics cards' efficiencies and prices are illustrated in Fig. 2. Figure 2(a) shows the results for ATI graphic cards. Fig. 2(b) illustrates the results for Nvidia cards and Fig. 2(c) compares the two. ATI cards' price and efficiency fluctuate dramatically between 0 to 2000 W/Gh/s except for the Radeon RX Vega 56, which is noticeably inefficient compared to the rest except for a sharp increase at the end. The most efficient and affordable cards identified from the ATI (Fig. 2(a)) are Radeon 5850, 5970 and 6990. As can be seen from Fig. 2(b), Nvidia's efficiency increases slightly from the beginning and gradually decreases up to the Tesla before growing significantly at the end. The price comparison has a similar behaviour for the Nvidia GTX 570 and has a sudden increase near Tesla s2070 and sudden drop at the end. According to Fig. 2(b), the most efficient Nvidia card is the Tesla s2070, however, it is also the most expensive. However, Fig. 2(c) clearly illustrates that the ATI cards are more efficient and cheaper than the Nvidia cards. Both brands consume a similar amount of power except the ATI Radeon 5870x6 (crossfire) and Nvidia Tesla s2070. Therefore, the cards' efficiency mainly depends on hash rates. As a result, investing in efficient ATI cards will help to gain more profits. Asics miners' results are illustrated in Fig. 3. Due to the rapid growth of cryptocurrency mining, there are several hardware manufactures which makes a comparison between them difficult. For instance, the efficiency comparisons have slight variations in every figure, and the price lines fluctuate from start to end. According to Fig. 3(a) BitmainAntminer s2 is the most expensive miner out of the Antminer series. It is not as efficient as the Antminer S9, which is the latest and most reasonably priced Bitmain product. From Fig. 3(b) the Avalon 6 miner is the most efficient miner out of Canaan series and costs under $1000. Sapphire miners, according to Fig. 3(c), are also inexpensive and cost under $100.00 However, the Sapphire is more efficient compared to the Blade. According to Fig. 3(d), KnC Neptune is almost three times more expensive than the Knc Jupiter. Although it is efficient and powerful, it has a higher hash rate and can solve complex algorithms. Fig. 3(e) contains more ASIC miners developed by different manufacturers. The Monarch BPU 600C is the most efficient and reasonably priced miner in the group. Comparing all the ASIC miners from Fig. 3(f), most of them are powerful, and they have their advantages and disadvantages. Though it is clear that BitmainAntminer S9 is the most efficient and affordable miner compare to the rest.

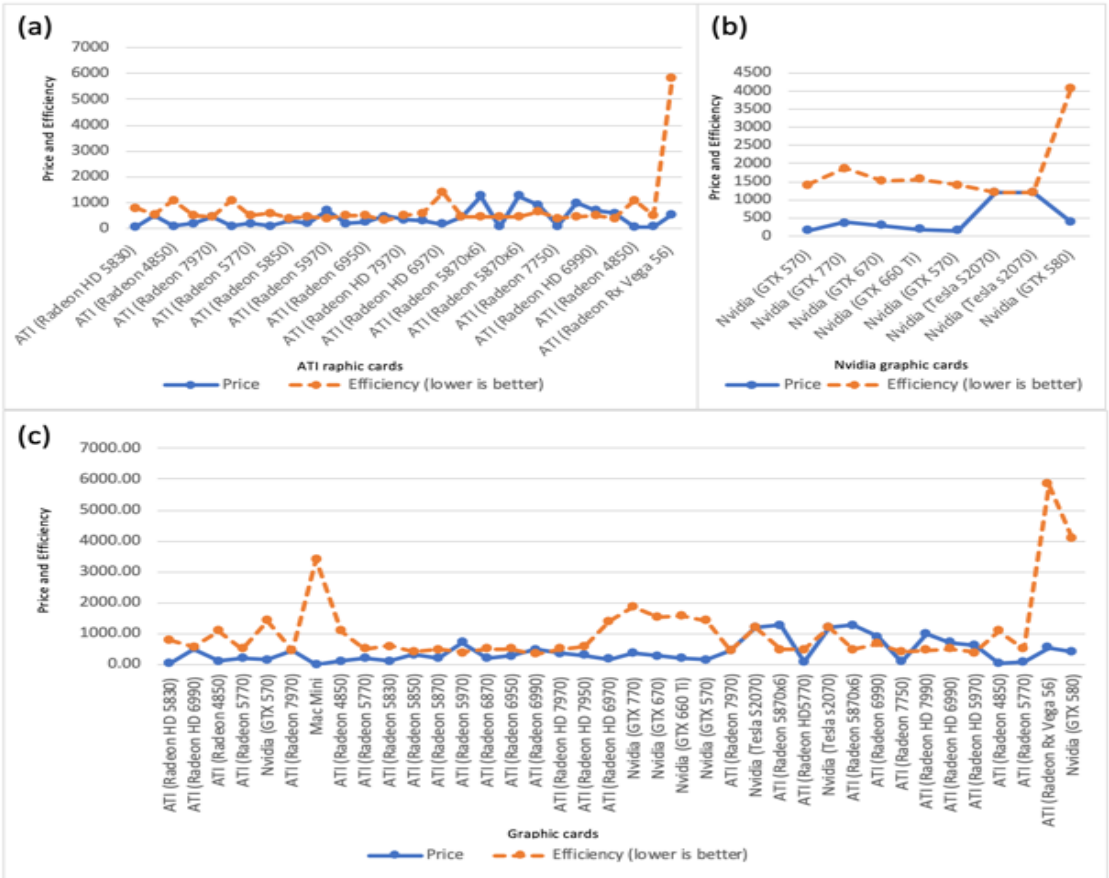

Fig.2. ATI and Nvidia graphics card (second-generation miners) comparisons to their prices and to their efficiencies. (a) for ATI, (b) for Nvidia and (c) for both GPUs. Graphics cards' efficiencies and prices were used from 30 papers. Please note, selected papers provided the power consumption and the hash rates. Therefore, efficiency is calculated using the following equation. Efficiency = Power consumption(W) / Hash rate(Gh/s). Plots indicate that price values are in solid blue lines, and efficiency values are in orange dotted lines.

Four different type of FPGA miners' efficiencies and prices are demonstrated in Fig. 4 using 30 peer review papers. All miners' results were analyzed from criteria a to c for each brand and Fig. 4(d) compares all the FPGA miners. Significantly, the ASIC and FPGA miners have similar efficiency values. However, price comparisons have sharp differences. For example, in Fig. 4(a), the Xilinx Spartan 6 is the most efficient but also the costliest compared to the Xilinx Spartan 6-150 miner. Similarly, the Butterfly Labs Mini Rig is more efficient than the Butterfly labs Single but again more expensive. The price comparison in Fig. 4(b) exhibits a rapid increase between Butterfly labs Single and Mini Rig miners. Fig. 4(c) illustrates two different studies about the DigilentNexys 2 500k. Both studies delivered similar efficiency values; nevertheless, there is a significant price difference. To conclude, after analyzing all the FPGA miners in Fig. 4(d), Xilinx Spartan 6 could be identified as the most affordable and efficient FPGA miner for Bitcoin mining.

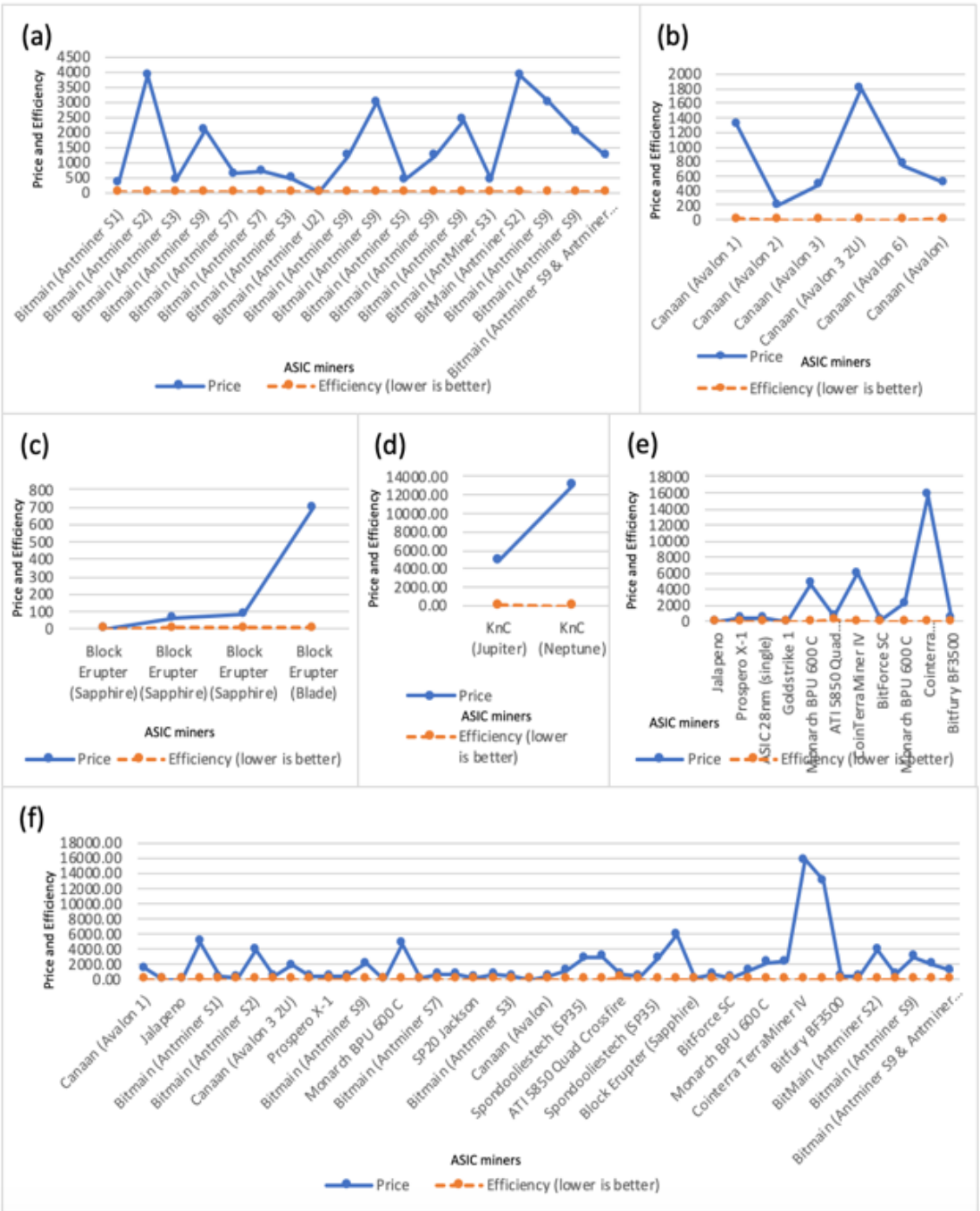

Fig.3. ASIC miner hardware compared to their prices and their efficiencies. (a) for Bitmain, (b) for Canaan, (c) for block, (d) for KnC, (e) for rest of the miners and (f) for all the ASIC miners. Values were obtained from 30 different studies. Certain papers provided the power consumption and the hash rates. Hence, efficiency is calculated using the Efficiency = Power consumption(W) / Hash rate (Gh/s) equation. Please note that price values are in solid blue lines and efficiency values are in orange dotted lines.

Cryptocurrency	Device Type	Hardware	Price USD	Released Date	Power Consumption (W)	Efficiency (W/Gh/s)	Hash Rate (Gh/s)	Study
Bitcoin	CPU	Intel (Xeon Phi 5100)	399.95	Nov-12	225	1607.14	0.14	Forte et al. (2015) [34]
Bitcoin	CPU	AMD (4x Opteron 6174)	3768.94	Sep-07	320	2782.6	0.115	Romano and Schmid (2017) [29]
Bitcoin	GPU	ATI (Radeon 5850)	324.00	Sep-09	314	398.94	0.787	Cocco and Marchesi (2016) [8]
Bitcoin	GPU	ATI (Radeon HD 5970)	599.00	Nov-09	294	392	0.75	Meiners (2013) [37]
Bitcoin	GPU	ATI (Radeon 6990)	480.00	Mar-11	375	328.95	1.139	Cocco and Marchesi (2016) [8]
Bitcoin	GPU	Nvidia (Tesla s2070)	1200.00	Nov-09	900	1201.6	0.749	Forte et al. (2015) [34]
Bitcoin	ASIC	Bitmain (Antminer S9)	3000.00	2017	1340	0.095	14000	Jamali et al. [40]
Bitcoin	ASIC	Canaan (Avalon 6)	750.95	2015-2016	1015	0.29	3500	Rodrigues [22]
Bitcoin	ASIC	Block Erupter (Sapphire)	66.99	-	2.55	7.65	0.333	Krishnan et al. (2015) [15]
Bitcoin	ASIC	KnC (Neptune)	12995.00	2014	2200	0.733	3000	McCook (2014) [14]
Bitcoin	ASIC	Monarch BPU 600 C	2196.00	-	350	0.58	600	Malone (2018) [39]
Bitcoin	FPGA	Xilinx (Spartan 6)	1995.00	Aug-09	10	45.45	0.22	Langland and Skordal (2015) [13]
Bitcoin	FPGA	DigilentNexys 2 500K	189.00	-	5	1000	0.005	Malone (2018) [39]
Bitcoin	FPGA	Butterfly Labs (Mini Rig)	22484.00	-	1250	49.6	25.2	Forte et al. (2015) [34]

Table 2: Most efficient and affordable hardware devices identified by individual manufacturer

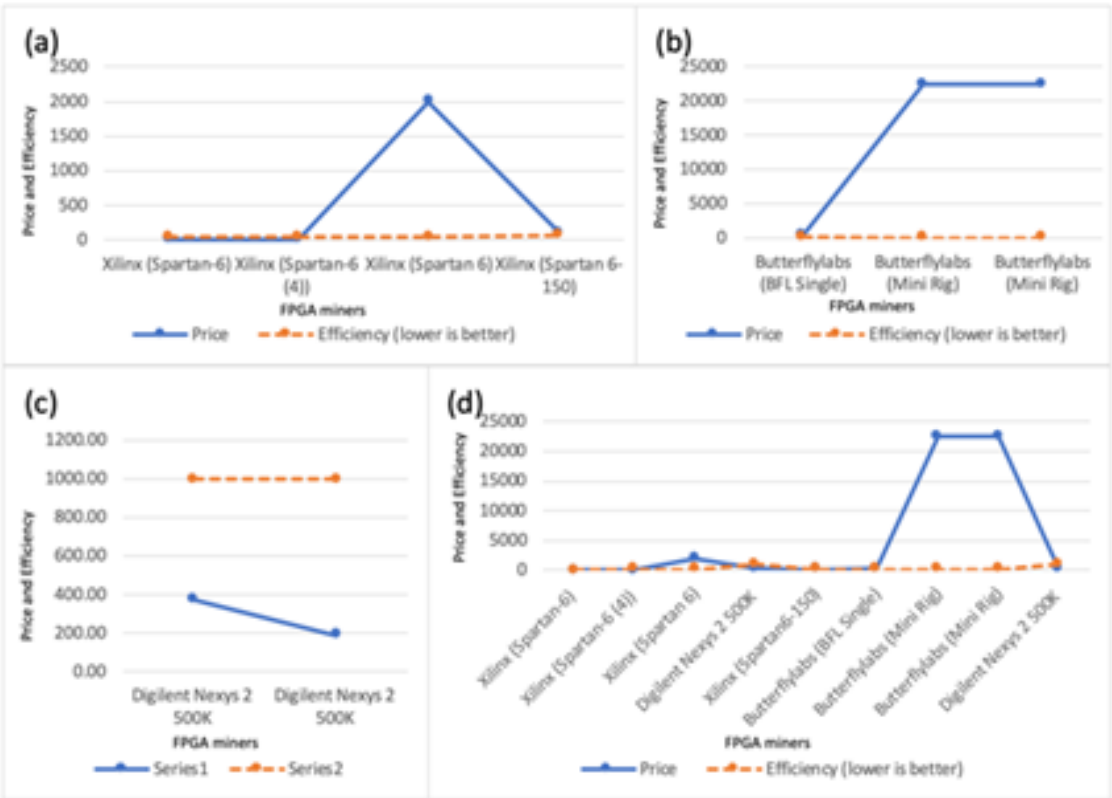

Fig.4. FPGA miners compared to their prices and their efficiencies. (a) for Xilinx, (b) for BFL, (c) for Digilent and (d) for all the FPGA miners. Plot data were acquired from 30 studies (from 2013 to 2018). Please note, several papers provided the power consumption and the hash rates. Therefore, efficiency is calculated using the following equation. Efficiency = Power consumption(W) / Hash rate (Gh/s). Price values are in solid blue lines, and efficiency values are in orange dotted lines.

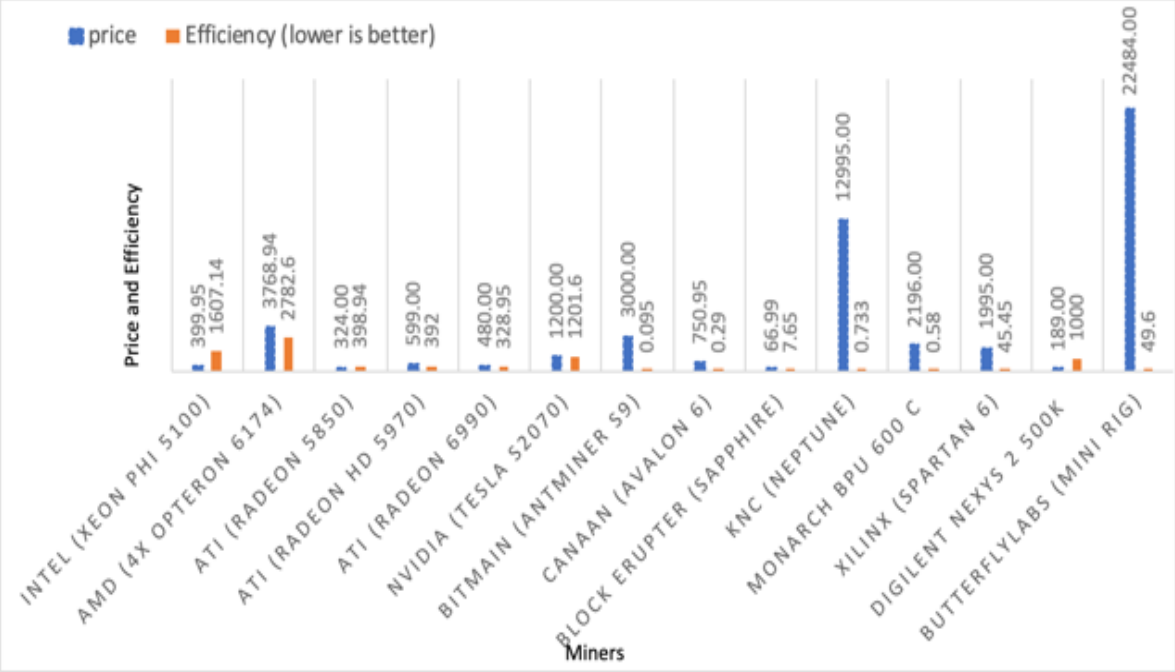

Fig.5. Intel, AMD, ATI, Nvidia, Bitmain, Canaan, Block erupter, KnC, Monarch, Xilinx, Digilent, Butterfly Labs manufacturers' most efficient miner's efficiencies and prices documented while analyzing our study.

IV. RESULTS

In this study, we examined a variety of hardware performance aspects from the early stage of Bitcoin mining to current customized mining. The choice of hardware is an essential factor to consider when mining Bitcoin due to the volatility of the Bitcoin price and the rising mining difficulty. New hardware costs a large amount of the mining income and miners must always buy the hardware with the lowest cost per Gh/s [12] to increase their chances of recovering the hardware cost as quickly as possible in order to gain profit.

Energy usage, hash rate and cost in each hardware were measured to identify the most suitable mining device. Through a combination of energy consumption and hash rate, we identified the efficiency of each hardware and compared with the cost to make sure the hardware must be able to earn more money than it uses. However, different authors used different methods to calculate efficiency. For instance, Krishnan et al. [15] calculated the hardware efficiency dividing the hash rates by power consumption; according to this equation, a higher efficiency value is better. The rest of the papers used in our work calculated the efficiency using the same values, although with a different technique. Therefore, (eq (1): Efficiency = Power consumption (W) / Hash rate (Gh/s)) was used to extract the hardware efficiencies obtained in Table S1.

A significant part of a miner's total costs come from hardware purchases. In order to start mining, the miner must initially buy the mining hardware. Mining hardware can be costly, with some FPGA miners such as Butterfly Labs Mini Rigs reaching up to tens of thousands of dollars. Therefore, it is essential that the mining hardware eventually pays for it.

To summarize, the identified hardware device data from each criterion was collected in Table 2 to develop Fig. 5 to identify the best mining hardware. KnC Neptune and Butterfly Labs Mini Rigs are high-priced compared to the other miners. CPU and GPU miners are not efficient enough while they are less expensive than the rest. According to Fig. 5, BitmainAntminer S9, Canaan Avalon 6, Block Erupter Sapphire, Monarch BPU 600 C are the most efficient and affordable miners. Considering the power consumption and computing power, which known as the hash rate gathered from Table 2, BitmainAntminer S9 is the appropriate hardware that currently exists for Bitcoin mining.

V. CONCLUSION

In this study, we performed a survey of the data obtained from 30 peer-reviewed articles from 2013-2018 describing 119 different hardware observations carried out in the scientific literature, which discuss the Bitcoin mining hardware performance from the deployment of Bitcoin cryptocurrency to currently available hardware in the market. After analyzing the scientific data, we have identified that BitmainAntminer S9 is currently the most excellent miner for cryptocurrency mining. Our survey also indicates that first-generation mining hardware (CPUs) can be ignored as a result of inefficiency and mining difficulty. Additionally, our results show ATI GPUs are efficient and inexpensive compared to Nvidia GPUs. Therefore, ATI GPUs can be used to assemble custom ASIC mining hardware such as

Mining Rigs. Moreover, this research could be useful as a reference for many researchers and miners to identify the common hardware efficiencies to maximize their mining profits in cryptocurrency.

AUTHOR CONTRIBUTION

A.P. and M.N.H. conceived the study idea and developed the analysis plan. A.P. analyzed the data and wrote the initial paper. M.N.H. helped to prepare the figures and tables and finalizing the manuscript. All authors read the manuscript.

REFERENCES

[1] Y. Liu, X. Chen, L. Zhang, C. Tang and H. Kang, "An Intelligent Strategy to Gain Profit for Bitcoin Mining Pools", Int. Symposium on Computational Intelligence and Design, vol. 10, p. 427, 2017.

[2] M. Bedford Taylor, "The Evolution of Bitcoin Hardware", Computer, vol. 50, no. 9, pp. 60-61, 2017.

[3] M. Salimitari, M. Chatterjee, M. Yuksel and E. Pasiliao, "Profit Maximization for Bitcoin Pool Mining: A Prospect Theoretic Approach", International Conference on Collaboration and Internet Computing, vol. 3, p. 271, 2017.

[4] O. Ala-Peijari, "Bitcoin the Virtual Currency: Energy Efficient Mining of Bitcoins", pp. 58-76, 2014.

[5] A. Kampl, "Bitcoin 2-Phase Immersion Cooling and the Implications for High Performance Computing", Electronics Cooling Magazine, p. 1, 2014.

[6] K. O'dwyer and D. Malone, "Bitcoin Mining and its Energy FootprintBitcoin Mining and its Energy Footprint", pp. 3-4, 2014.

[7] L. Cocco and M. Marchesi, "Modeling and Simulation of the Economics of Mining in the Bitcoin Market", PLOS ONE, vol. 11, no. 10, p. 7, 2016.

[8] J. Lee and Y. Kim, "An Analysis of Energy and Hardware Impacts on the Bitcoin Mining Network", ACM Transactions on Economics and Computation, vol. 5, no., pp. 1-10.

[9] M. N. Halgamuge, M. Zukerman, R. Kotagiri, and H. Vu, "An Estimation of Sensor Energy Consumption", Progress In Electromagnetics Research B, Volume 12, 259-295, Jan. 2009

[10] M. N. Halgamuge, S. M. Guru, and A. Jennings, "Centralized Strategies for Cluster Formation in Sensor Networks", Classification and Clustering for Knowledge Discovery, Springer-Verlag, ISBN: 3-540-26073-0, Chapter 20, pp. 315-334, Aug 2005

[11] M. N. Halgamuge, "Efficient Battery Management for Sensor Lifetime", Proceedings of IEEE 21st International Conference on Advanced Information Networking and Applications (AINA'07), Volume 1, pp 56-61, Niagara Falls, Canada, 21-23 May 2007.

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