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AN ANALYSIS OF EVOLUTIONARY CRYPTOCURRENCY MARKET DYNAMICS

EVRIMSEL KRIPTO PARA PIYASASI DINAMIKLERI ANALIZI

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Abstract

The focus of this research is to describe and discuss future blockchain technology in relation to different forms of digital cryptocurrencies by investigating distinct characteristics and common features of cryptocurrencies on the market. This research explores significant relationships between the major cryptocurrencies on the complex cryptocurrency market ecosystem, particularly Bitcoin and the most prominent altcoins based on historical market capitalization data for the last two years. In this work cross-correlations between different cryptocurrencies are examined in terms of changes in the market capitalization value. For the comparative analysis minimum spanning tree (MST) and hierarchical structure tree (HST) methods are applied in the context of economic behaviour of cryptocurrencies with regard to global cryptocurrency market trends.

Keywords: Blockchain; Cryptocurrencies; Correlation matrix; Minimum spanning tree; Hierarchical structure tree

Öz

Bu araştırmanın amacı, kripto para piyasadaki kripto para birimlerinin ortak özellikleriyle birlikte farklı özelliklerini araştırmak, gelecekteki blokzinciri teknolojisin birbirinden farklı kripto para birimleri üzerinde etkileşimini tartışmaktır. Bu araştırma, karmaşık bir yapıya sahip olan kripto para piyasası ekosistemindeki başlıca kripto para birimi olan Bitcoin ve son iki yıl içerisinde verilere dayanarak kripto para piyasında değer kazanan altcoin'ler arasındaki ilişkileri incelemektedir. Yapılan çalışmada, kripto para birimlerinin fiyat değişimleri arasında çapraz korelasyon olup olmadığı, kripto para piyasası ekososteminin kapitalizasyon değerindeki değişiklikler açısından araştırılmıştır. Araştırmada kullanılan veri setini karşılaştırmalı analize uygulayarak, kripto para birimlerinin ekonomiksel davranışları incelenmiş, bu bağlamda küresel kripto para birimlerinin piyasa eğilimlerini inceleyerek asgari Yayılma Süreci (Minimum spanning tree) ve Analitik Hiyerarşi Süreci (hierarchical structure tree) yöntemleri kullanılmıştır.

Anahtar Kelimeler: Blokzinciri; Kayıtzinciri; Kripto Paralar; Korelasyon Matrisi; Asgari Yayılma Ağacı; Analitik Hiyerarşi Süreci

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1. INTRODUCTION

Cryptocurrencies are digital assets that use cryptography to work as a medium of exchange. Generating of additional units, which are finite in number, requires solving encryption algorithms. An encrypted, digital ledger, called a "***Blockchain***", is being used to record transactions and balances. It is devised as a part of the first cryptocurrency (Bitcoin)'s invention (Nakamoto, 2008). The Blockchain is a public transaction database functioning as a distributed ledger. It is defined as "record of all validated transactions grouped into blocks, each cryptographically linked to predecessor transactions down to the genesis block, thereby creating a chain of blocks" (Hileman & Rauchs, 2017). By design, along with the increasing number of transactions that are contained by the blocks, the entire blockchain transforms into more complex structure and this structure does not have a particularly central position or an owner. Thereby, instead of having a central authority, the validation of the transactions is supplied by the whole network. Accordingly, every transaction, balances and history in the chain is open for viewing and users are anonymous (Hileman & Rauchs, 2017). These features create uniqueness for the blockchain as compared to other database systems. Due to its unique feature's cryptocurrencies have a reputation for its advantageous position in today's finance world in many aspects. In fact, some authorities believe that it could be the biggest technological development since the Internet (Burniske & White, 2016).

The blockchain mechanism provides a special validation process for transactions which is provided by the whole chain without a central authority (Öncü, 2019). Hence, a cryptocurrency transaction cannot be modified, since transactions cannot be validated without consensus. Additionally, along with the continuous growing list of blocks, a blockchain becomes more resistant to modification of the data (Bruyn, 2017). This provides a secure, risk-free environment for cryptocurrencies (Uygun, 2019).

Under favour of decentralization idea behind the blockchain technology, cryptocurrencies could be sent between peers using electronic wallets without an intervention of any third party like banks and governments. In parallel with this concept, a commonly agreed record of truth provided by the blockchain technology to multiple and mutually distrusting participants in an economic system brings fundamental benefits (Casey, Crane, Gensler, Johnson & Narula, 2018). These benefits are derived by virtue of "removing the requirement for participants to trust a particular person or entity to maintain that record on their behalf, opening the door to more direct, peer-to-peer (or machine-to-machine) transactions or to the independent execution of smart contracts" (Casey, Crane, Gensler, Johnson & Narula, 2018). In addition to excluding third parties, cryptocurrencies have some other advantages like low fees, fast settlements, high security, anonymousness and easy access comparing to fiat currencies. Yet another favourable feature underlying the idea of introducing the new cryptocurrencies stems from avoiding the inflation phenomena as often happens for "fiat" currencies (Cocco, Concas & Marchesi, 2015). Along with the features they have, cryptocurrencies became very popular during recent years.

With receiving a great deal of interest for the last several years, cryptocurrencies become the focus of physicists as well as economists (Stosic, Stosic, Ludermir & Stosic, 2018). Since cryptocurrencies as a branch of financial markets are considered as complex systems, these complicated mechanisms have been extensively studied by physicists via using different conceptual and methodological approaches to describe physical systems (Jovanovic, Mantegna & Schinckus, 2018). In order to investigate reasonable relationships and discover meaningful patterns among different types of cryptocurrencies alternative appropriate methods including partial correlations, cross-correlations, minimum spanning tree and hierarchical tree structure methods are applied for the analysis of cryptocurrency market dynamics. Studies that aim to examine correlations between different financial assets are not

only a topic of interest for scientific reasons of understanding the economy as a complex dynamical system, but also for practical reasons such as quantifying the risk of investment portfolios (Jones, 1985).

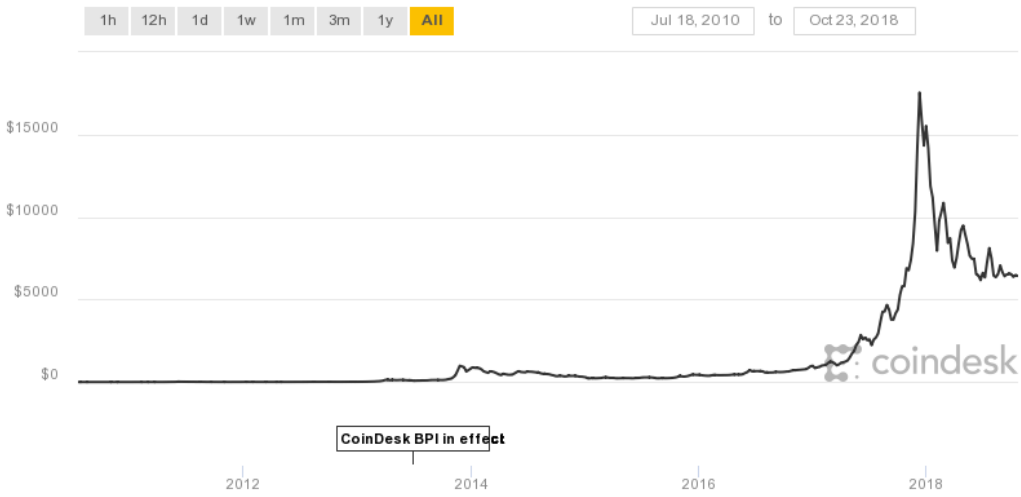
For conducting a research associated with the cryptocurrencies one of the main issues that remain a challenge is finding a reliable and proper database to gather information for the analysis. When it comes to financial data, the decision given to determine an appropriate database becomes more difficult due to market volatility of the financial environment. In this respect, based on instantaneous changes on the market conditions and unstable market structure, historical data obtained from databases considered as finite and at this point researchers concentrate on correlations between financial time series to reveal that whether it results from omnipresent dynamical noise or genuine interactions (N. & Wold, 1939).

1.1. THE KING OF ALL COINS: BITCOIN

Bitcoin, which is developed by an anonymous person or a group of people under an alias "***Satoshi Nakamoto***" in 2009, is the first cryptocurrency. It is initially being introduced in the paper that is written by Satoshi Nakamoto on 31 October 2008. Satoshi Nakamoto describes Bitcoin as "*A peer-to-peer Electronic Cash System*" in the paper (Nakamoto, 2008).

On 12 January 2009 Nakamoto sent 10 Bitcoin to Hal Finney, a computer programmer, which is recorded as the first cryptocurrency transaction (Peterson, 2014). In 2010, Bitcoin is used as a monetary value first time when a Bitcoin owner orders two pizzas and pays 10,000 coins for them (Bigmore, 2018).

These would be the most expensive pizzas in history taking into consideration the current value of Bitcoin. In 2011, new cryptocurrencies begin to show up. Following years, a number of cryptocurrencies continue to increase along with the popularity and use of them. In 2017, from the beginning of the year to the end of the year Bitcoin showed a spectacular rise. It rose from about $930 to $19,783 in December 2017 according to CoinDesk Bitcoin Price Index ("*Bitcoin Price Index — Real-time Bitcoin Price Charts*", 2019).



Source: Coindesk

Figure 1. Bitcoin all time price rise (in USD)

1.2. ALTCOINS

In the recent period of the cryptocurrency market, it can be clearly seen that the number of cryptocurrencies has increased rapidly. However, "the majority of cryptocurrencies are largely clones of Bitcoin or other cryptocurrencies and simply feature different parameter values" that are particularly different block time, currency supply, and issuance scheme (Hileman & Rauchs, 2017). The rise in the market value of the Bitcoin, which is the most dominant cryptocurrency by the market capitalization, has a significant impact on the growing trend of the number of cryptocurrencies. Therefore, much research conducted in the cryptocurrency field mainly focuses on Bitcoin and analysis of its behaviour on the market. Similarly, it is highlighted that the increasing trend of Bitcoin *"has triggered large interest not only among virtual currency users and investors but also in the scientific literature that has analysed extensively the price formation of Bitcoin"* (Ciaian, Rajcaniova & Kancs, 2018). On the other hand, today, there are hundreds of cryptocurrencies available on the market with a value that enable trading. Thus, one of the objectives of this study is to examine the relationship between different cryptocurrencies in order to find out reasonable results in many aspects supported by particular financial analysis techniques. In this context, to explore major characteristics and distinctive features of cryptocurrencies, especially digital currencies that are not Bitcoin, will be taken into consideration and analysed in details. Since Bitcoin maintain its dominant position in terms of market capitalization and exchange volume for a long time, other cryptocurrencies are mostly regarded as alternative cryptocurrencies to Bitcoin and named as altcoin. In other words, as (Farell, 2015) introduces that the term altcoin is referred to as non-Bitcoin or post-Bitcoin cryptocurrencies. The superiority of Bitcoin in terms of market share leads the developers of alternative cryptocurrencies to improve certain features of cryptocurrencies. Hence, *"in order to compete with the market leader Bitcoin, the developers of altcoins have understandably emulated its best features, while introducing various general improvements and customizations"* (White, 2014). These improvements mainly focus on security-related subjects, ease of use during financial operations, improving the speed of transactions and reducing the prices of additional fees.

Altcoins are often associated with Initial Coin Offering (ICO) which is a way for a new coin that launched on the market recently to raise fund by offering pre-sale of the new project's tokens in exchange for existing cryptocurrencies such as Bitcoin or Ether. Li and Mann's study provided that "*in a typical initial coin offering (ICO), an entrepreneur pre-sells digital tokens which will later serve as the medium of exchange on a peer-to-peer platform*" (Li & Mann, 2018). Thereby, investors and traders' approach to the ICO concept could be defined as an investment opportunity for altcoins which have a long-run growth potential. The logic behind the ICO concept is directly associated with the growth behaviour of new cryptocurrencies in the development phase. Hence, a venture usually starts by creating a plan on a whitepaper to benefit from the ICO as a way to raise money. In brief, whitepaper of a specific project includes the subject of the project, needs and requirements of the project, the amount of money needed to accomplish the project, and the ICO time period for the project completion. At the end of the specified time period in an ICO stage, *"if the total purchases exceed the minimum threshold, the entrepreneur proceeds with the venture, otherwise all contributions are returned, the venture does not launch and the game ends"* (Catalini & Gans, 2018).

Before going into details, as of 2018, three of top ten cryptocurrencies by market capitalization will be identified and investigated briefly in this section to give a general overview of the digital currencies. For this reason, altcoins that are having a market value above a certain level which in this case Ethereum and Ripple with having a market capitalization greater than ten million dollars will be considered to review in details.

Moreover, Litecoin, which is located at a breaking point to reach a level which involves more than one million dollars value band by market capitalization, has an important place, therefore, Litecoin will be analysed as third special altcoin involved in the top ten list.

1.2.1. ETHEREUM

Ethereum is known as the most prominent decentralized software platform that provides a basis for smart contracts and distributed applications to ensure cryptographically-secured transactions. Wood (2014) states that Ethereum is essentially a transaction-based state machine mechanism. The Ethereum platform uses Ether (ETH) as specific cryptocurrency on its blockchain network. Ethereum has a reputation for reducing the transaction processing time by using powerful specialized hardware in the network (Yi, Xu & Wang, 2018). Although the Ethereum blockchain differs from other cryptocurrencies by means of smart contract mechanism and particular transaction system, the platform has some difficulties due to the complexity of performing financial transactions between parties with respect to ordinary payment systems. One of the main reasons for the complexity that the Ethereum platform faces, arises from its proof-of-work mechanism. For this issue, (Farell, 2015) noted that "*a major criticism of the proof-of-work mechanism is the massive amounts of energy it consumes, with no other benefit than to verify transactions*". Under this mechanism, smart contract framework and secure transaction execution structure are in a way building partial blockchain regulation in itself. According to Wood (2014) *"Ethereum may be seen as a general implementation of such a crypto-law system"*.

1.2.2. RIPPLE

Another digital asset is called Ripple that has launched in 2012 as an open payment network. It is known as one of the cryptocurrencies that does not have a blockchain but instead uses a 'global consensus ledger' (Hileman & Rauchs, 2017). In the Ripple consensus algorithm, the notion of "consensus" defined as "the state in which nodes in the network reach agreement" (Schwartz, Youngs & Britto, 2014). The network specific cryptocurrency for the Ripple is denoted as XRP. The main purpose of the network is providing a global money transfer mechanism without paying a high amount of transaction fees. At the same time, the system offers a real-time processing for payments based on the principle of transparency. The Ripple is quite different from Bitcoin in terms of mining mechanism. The ripple network does not involve mining so that it uses the relatively small amount of computer power and provides faster transactions. Orcutt (2018) specifies that Ripple's crypto-token XRP as "*a bridge currency that financial institutions use to settle cross-border payments faster and more cheaply than they do*".

1.2.3. LITECOIN

Litecoin is known as one of the most crucial digital coins which launched on October 7, 2011 by Charlie Lee, a Google employee and former Engineering Director at Coinbase (Wikipedia, 2019). In contrary to Bitcoin, the Litecoin's algorithm does not require advanced and expensive hardware for mining coins. By this way, the Litecoin makes mining process possible even with regular computers. Since the number of performance requirements for the system decreases, the network costs substantially reduced. Moreover, through a simpler algorithm, Litecoin achieves four times faster block generation and transaction processing. Another key differentiation of the Litecoin is that the system has a maximum coin limit of 84 million where the Bitcoin has the maximum limit of 21 million coins. On the other hand, Orcutt (2018) emphasizes about the downsides of the network that "*though faster than Bitcoin, Litecoin is still too slow and energy-hungry to be an ideal payment method, and it has the added handicap of being far less well-known*".

Table 1. Table demonstrates the list of comparison of top ten cryptocurrencies by market capitalization.

Number	Logo	Name	Symbol	Release Date	Blocks Generation Mechanism	Maximum Supply	Mineable	Market Capitalization	Average Transaction Speed	Block Creation Time
1		BITCOIN	BTC	2009	Proof of Work	21 Million	Yes	$ 112.341.934.258	78 minutes	10 minutes
2		ETHEREUM	ETH	2015	Proof of Work	Unlimited	Yes	$ 21.013.531.753	6 minutes	15-17 seconds
3		RIPPLE	XRP	2012	Byzantine Consensus	100 Billion	No	$ 17.987.239.419	4 seconds	3-5 seconds
4		BITCOIN CASH	BCH	2017	Proof of Work	21 Million	Yes	$ 7.704.907.720	60 minutes	10 minutes
5		EOS	EOS	2018	Proof of Stake	1 Billion	No	$ 4.902.415.429	1.5 seconds	-
6		STELLAR	XLM	2017	Proof of Stake	100 Billion	No	$ 4.566.513.632	5 seconds	-
7		LITECOIN	LTC	2011	Proof of Work	84 Million	Yes	$ 3.090.502.026	30 minutes	2.5 minutes
8		TETHER	USDT	2014	Proof of Reserves	3 Billion	No	$ 1.999.923.657	-	-
9		CARDANO	ADA	2015	Proof of Stake	45 Billion	No	$ 1.933.469.046	5 minutes	-
10		MONERO	XMR	2014	Proof of Work	Unlimited	Yes	$ 1.794.560.152	30 minutes	2 minutes

Source: Table created by authors (Nakamoto, 2009, Ciaian and Rajcaniova, 2018, Wood, 2014, Nica et al., 2017).

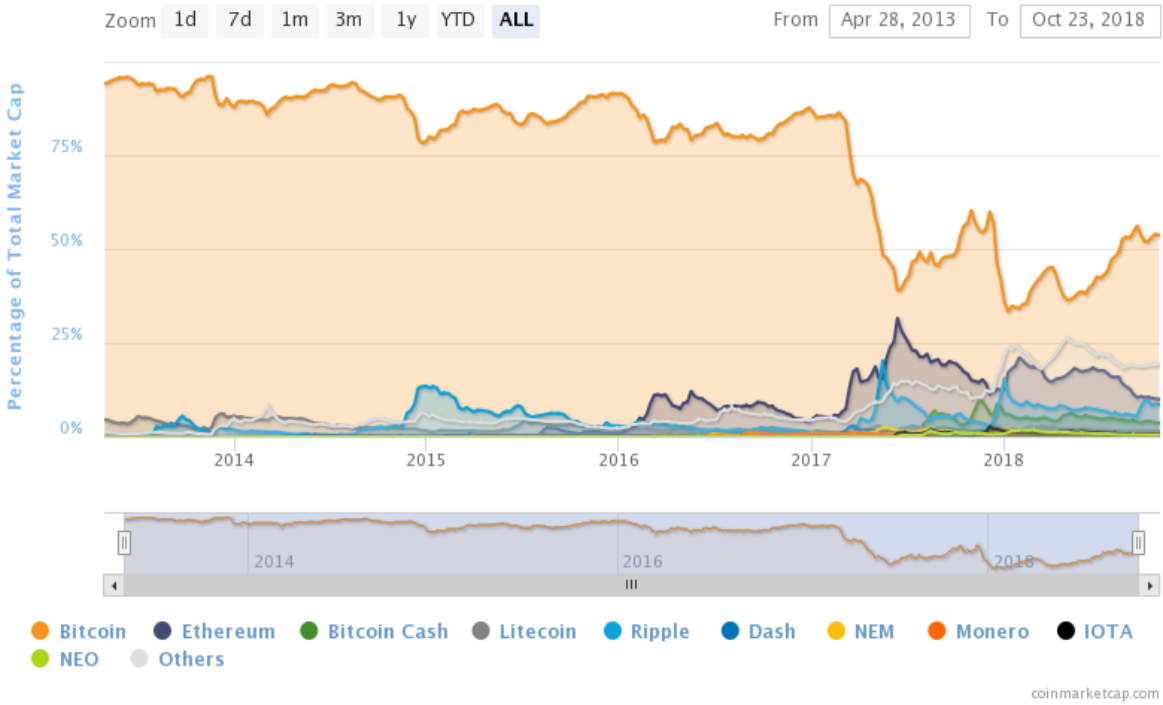
2. THE GLOBAL CRYPTOCURRENCY MARKET: DIGITALIZATION

The focus of this research is also exploring the dynamics of cryptocurrencies to find out significant changes of the cryptocurrencies on the market by means of historical data analysis.

When the total market capitalization of the cryptocurrencies is considered as an important indicator in Figure 2, it can be said that the total market capitalization reached the peak in January 2018 with the total value of approximately 830 billion dollars ("Global Charts | CoinMarketCap", 2018). The figure shows that in January 2017 the total value was nearly 17 billion dollars which were clearly revealed the dramatic increase in the total market capitalization. However, today the total market value substantially decreased and reached the total market value of 209 billion dollars. In the present case, the total market value of the cryptocurrencies is still in a considerably certain level with respect to the total market value of previous years. Nonetheless, the market experiences panic mode along with the significant price falls at times.

Source: Coinmarketcap

Figure 2. The total market capitalization of cryptocurrencies.



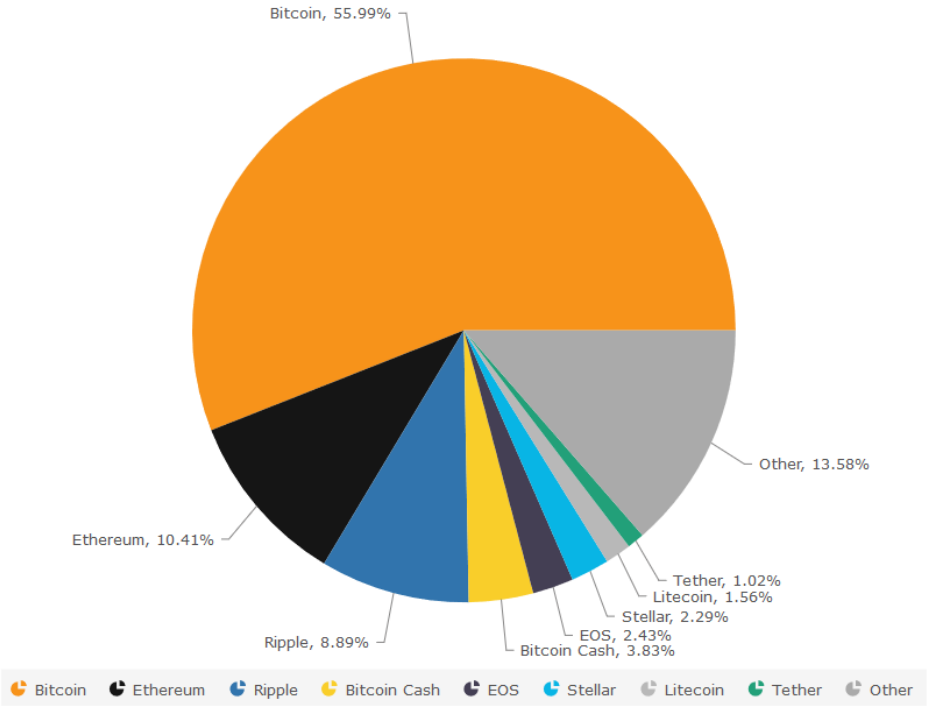
Source: Coinmarketcap

Figure 3. Percentage of total market capitalization of cryptocurrencies

In Figure 3, percentage rates of cryptocurrencies by market capitalization were demonstrated in a yearly distribution ("*Percentage of total market capitalization of cryptocurrencies*", 2018). From the historical perspective, it can be seen that Bitcoin has a dominant position in terms of market capitalization percentage among all cryptocurrencies.

The figure shows that Ethereum became the second most valuable position on the market by market capitalization after its introduction in 2015.

Figure 4 indicates that the percentage distribution of each cryptocurrency on the market by market capitalization ("The total cryptocurrencies by market capitalization", 2018). Based on the data retrieved today (October 23, 2018) from the coin dance statistics, it is obvious that the total value of cryptocurrencies other than Bitcoin listed in the top ten list by market capitalization could not reach the total value of Bitcoin by itself. The leading cryptocurrency in the figure is Bitcoin with a rate of 55 %. Ethereum follows Bitcoin with a rate of 10 % and Ripple in the third place with a rate of 8 %.



Source: Coindance

Figure 4. The total cryptocurrencies by market capitalization.

According to the cryptocurrency market statistics data obtained from cryptoindex database ("*The cryptocurrency market statistics*", 2018), we can conclude that as of 23rd October 2018, the total number of active cryptocurrencies is 895 and the number of the market is over 15.000. The numbers infer that the popularity of cryptocurrency market is still in the growth trend based on the data gathered from the historical cryptocurrency market statistics.

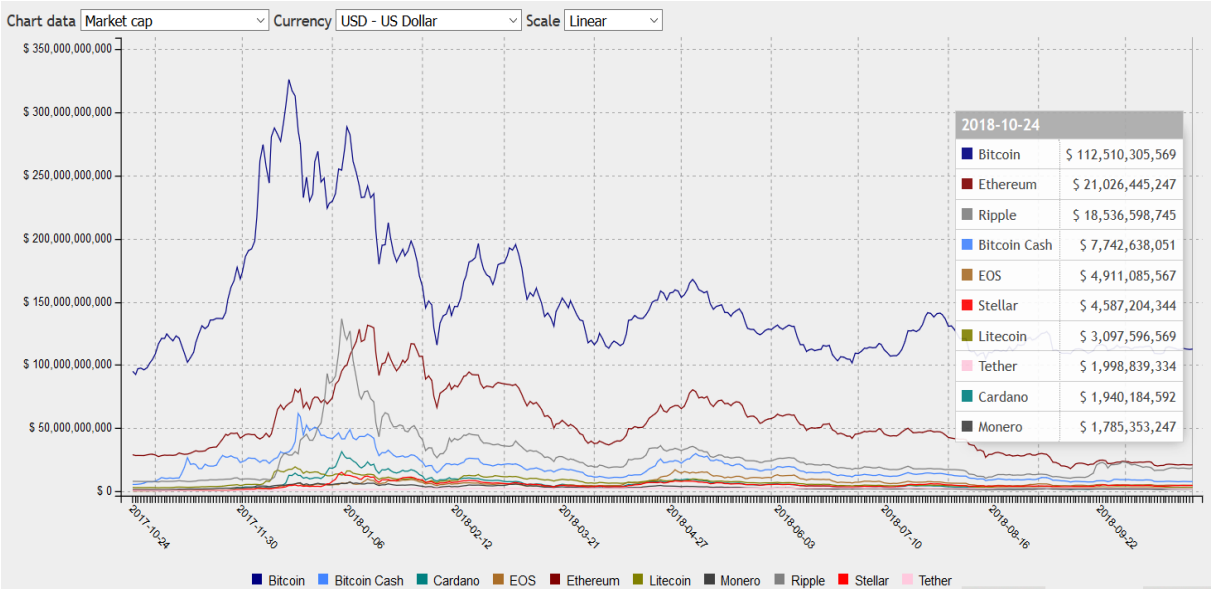
In Figure 5, market capitalization includes total coins in circulation plus the current market price where the price value in the figure involves the current average market price across exchanges ("*Top 10 cryptocurrencies by market capitalization*", 2018). Volume column contains the value that represents how much of a coin was traded in the past 24 hours. In this regard, Bitcoin differs from other cryptocurrencies with a sharp rate reaching three digit amount of value by market cap. The second and the third most valuable cryptocurrencies Etherum and Ripple also differs from the rest of the list by reaching two-digit values in terms of market capitalization.

#	Name	Market Cap	Price	Volume (24h)	Circulating Supply	Change (24h)	Price Graph (7d)
1	Bitcoin	$112.341.934.258	$6.479,41	$3.693.074.558	17.338.300 BTC	-0,04%	
2	Ethereum	$21.013.531.753	$204,50	$1.233.790.920	102.755.243 ETH	0,19%	
3	XRP	$17.987.239.419	$0,449708	$319.581.668	39.997.634.397 XRP *	-0,63%	
4	Bitcoin Cash	$7.704.907.720	$442,34	$265.502.535	17.418.500 BCH	-1,09%	
5	EOS	$4.902.415.429	$5,41	$329.875.578	906.245.118 EOS *	0,46%	
6	Stellar	$4.566.513.632	$0,241682	$38.337.645	18.894.758.343 XLM *	0,43%	
7	Litecoin	$3.090.502.026	$52,51	$266.319.707	58.852.502 LTC	0,49%	
8	Tether	$1.999.923.657	$0,986924	$2.095.576.972	2.026.421.736 USDT *	0,15%	
9	Cardano	$1.933.469.046	$0,074573	$20.689.749	25.927.070.538 ADA *	-1,60%	
10	Monero	$1.794.560.152	$108,68	$20.429.500	16.512.022 XMR	3,79%	

Source: Coinmarketcap

Figure 5. Top 10 cryptocurrencies by market capitalization

In a similar manner, distribution of top ten cryptocurrencies can be viewed from Figure 6 ("*Top 10 cryptocurrencies by market capitalization*", *2018*). For example, each cryptocurrency has a marginally different character and function from the people's favourite, bitcoin, to the banking focused on Ripple XRP.



Source: Cryptocurrencychart

Figure 6. Top 10 cryptocurrencies by market capitalization

3. OBJECTIVE OF THIS RESEARCH

There are several reasons why this topic has been chosen mainly popularity of cryptocurrencies, the popularity of data science and the possibility of creating a value by combining these two. In this manner, it is planned to bring out some suggestive outcomes as a conclusion of this research.

The objective of the study is to reveal relations between cryptocurrencies. Accordingly, MST and HT algorithms are applicable methods to investigate hierarchical structures and present connections between them (Ulusoy et al., 2012). To determine minimum spanning trees connecting cryptocurrencies chosen in the research, it is required to use distances between them. Mantegna and Stanley state that, because the correlation coefficient is not a metric expression, it cannot be used as a distance. Their methodology suggests calculating correlation coefficients of pairs initially and distances after then (Mantegna, 1999). Following their methodology, cross-correlations between price changes of cryptocurrencies are quantified. In order to quantify them, daily price change rates $(\xi_i(t))$ of cryptocurrency $i = 1,2, \dots, n$ at day t are calculated firstly.

$$\Delta S_i(t) = S_i(t) - S_i(t-1) \quad (1)$$

$$\xi_i(t) = \Delta S_i(t) \,/\, S_i(t) \quad (2)$$

where $S_i(t)$ is the closing price of the cryptocurrency i at the day t, $S_i(t-1)$ is the closing price of the cryptocurrency $i$at previous day and $\Delta S_i(t)$ is the difference between them. Using the daily rate of changes, the correlation coefficient, known as Pearson's correlation or Pearson's r, of a pair of cryptocurrency prices can be calculated as following (Hall, 2015).

$$r_{ij} = \frac{C(\xi_i \xi_j)}{\sigma_i \sigma_j} \quad (3)$$

For time interval $1, \dots, t$ the formula is given in more detail as following,

$$r_{ij} = \frac{\sum_1^t (\xi_i(t) - \bar{\xi_i})(\xi_j(t) - \bar{\xi_j})}{\sqrt{\sum_1^t (\xi_i(t) - \bar{\xi_i})^2 (\xi_j(t) - \bar{\xi_j})^2}} \quad (4)$$

where

$$\bar{\xi_i} = \frac{1}{N}\sum_t \xi_i(t) \,,\, \bar{\xi_j} = \frac{1}{N}\sum_t \xi_j(t) \quad (5)$$

where σ_i and σ_j are variance of closing cryptocurrency prices S_i and S_j and $C(\xi_i \xi_j)$ is the covariance of prices respectively. $r_{ij} = 1$ means prices of cryptocurrency i and j are perfectly correlated and $r_{ij} = -1$ corresponds to cryptocurrency i and j are completely opposite-correlated. Cryptocurrencies are uncorrelated if $r_{ij} = 0$.

3.1. DATA

In order to calculate correlations, a coin list and price histories of coins are needed. These will be provided with two APIs. Daily closing prices of cryptocurrencies are retrieved from CoinMarketCap API ("CoinMarketCap API", n.d.). Currently, there are 2003 coins in the list. Top 10 currencies ranked by market cap are listed in Table 2.

Table 2. Top 10 cryptocurrencies ranked in CoinMarketCap

Symbol	Name	Symbols	Rank	Price ($)
	Bitcoin	BTC	1	6488.385
	Ethereum	ETH	2	214.1688
	Ripple	XRP	3	0.514217
	Bitcoin Cash	BCH	4	596.4779
	EOS	EOS	5	5.548938
	Stellar	XLM	6	0.252038
	Litecoin	LTC	7	53.39051
	Cardano	ADA	8	0.077015
	Monero	XMR	9	110.6021
	Tether	USDT	10	0.992477

For the top 200 coins, calculations will be made and the price histories of those coins are gathered with CryptoCompare API ("CryptoCompare API", 2018). Price history of 193 of 200 coins are available with that API. A sample of first 10 rows of BTC price history is shown in Table 3.

"Data Close" is the daily cryptocurrency closing price as it is shown on the Table 3 as t and previous price on the table as $t-1$.

Table 3. Top 10 daily prices of BTC in CryptoCompare.

Day Rank	Symbol	Coin	Data Time	Data Close	Previous Price
1		BTC	6/26/2017	$2446.05	NA
2		BTC	6/27/2017	$2583.75	$2446.05
3		BTC	6/28/2017	$2577.74	$2583.75
4		BTC	6/29/2017	$2558.37	$2577.74
5		BTC	6/30/2017	$2480.61	$2558.37
6		BTC	7/1/2017	$2424.61	$2480.61
7		BTC	7/2/2017	$2536.46	$2424.61
8		BTC	7/3/2017	$2572.47	$2536.46
9		BTC	7/4/2017	$2617.32	$2572.47
10		BTC	7/5/2017	$2627.86	$2617.32

Correlations between a pair of cryptocurrencies are calculated using price change percentage vectors of combinations of currency pairs. After a full history of price changes are

obtained, currencies having last 500 days of price data are filtered and top 50 of them are selected with respect to their market cap rank. In Table 4, a list of selected currencies can be seen.

Table 4. Selected currencies after pre-process.

AE	DCR	KMD	PAY	XEM
ARDR	DGB	LKY	PIVX	XIN
ARK	DGD	LSK	POLY	XLM
BCN	DOGE	LTC	RDD	XMR
BNT	DROP	MAID	REP	XRP
BOS	EOS	MCO	SC	XTZ
BTC	ETC	MONA	SNT	XVG
BTS	ETH	NAS	STEEM	XZC
CMT	FCT	NEC	STRAT	ZEC
DASH	FUN	NXT	VERI	ZEN

For each day of each currency price change percentages are calculated using the closing price of the day and the previous day.

In Figure 7, cross-correlations between cryptocurrencies in this research are represented. Dark blue means a high positive correlation is present between a pair of cryptocurrencies, while dark red means a high negative(opposite) correlation is present.

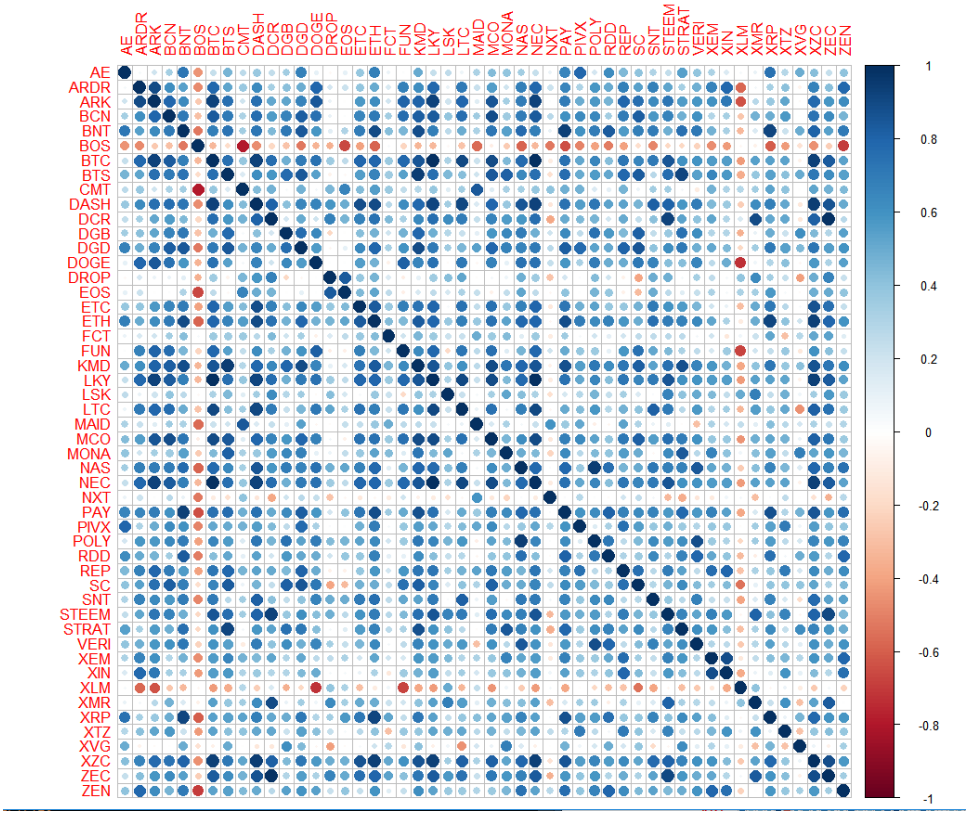


Figure 7. Cross-correlations calculated between cryptocurrencies.

For instance, BOS has a high opposite correlation with most of the currencies while BTC has a high correlation. Having a high correlation means that distance between the pair of

cryptocurrencies would be low and a cryptocurrency which has lower distances with most of the other cryptocurrencies is more likely to have a central role in the graph of MST. Because its distance is lower, and it will probably be connected in MST graph. On the other hand, a currency having high opposite correlations with most of the other cryptocurrencies will have higher distances with other currencies. This means that this currency is more likely to be on the outer boundaries of the graph.

3.2. FUNDAMENTALS OF MST AND HT STRUCTURES

As stated above, the initial approach is to calculate cross-correlations of the price changes in numerous cryptocurrencies. Correlations could be helpful to measure the degree of association between two cryptocurrencies. However, to analyse the entire network it is required to apply more sophisticated tools such as Minimum Spanning Tree (MST) and Hierarchical Tree (HT) algorithms.

Minimum Spanning Trees (MST) is based on minimizing the sum of edges among all spanning trees in the complex network. To get MST, it is required to convert correlation matrix provided above to a metric distance matrix. The Euclidean distance between two vectors namely $\overrightarrow{v_i}$ and $\overrightarrow{v_j}$ is calculated by using Pythagorean relation stated below.

$$d_{ij}{}^2 = \left\|\overrightarrow{v_i} - \overrightarrow{v_j}\right\|^2 = \overrightarrow{v_i}^2 - \overrightarrow{v_j}^2 - \overrightarrow{v_i}\overrightarrow{v_j} \quad (6)$$

Accordingly,

$$d_{ij} = \sqrt{2(1 - \xi_i \xi_j)} \quad (7)$$

$$d_{ij} = \sqrt{2(1 - r_{ij})} \quad (8)$$

An MST algorithm is capable of detecting clusters between connections of data patterns (Zahn, 1971). By detection of clusters, it is possible to construct an HT using shortest paths obtained from MST. In this research, Kruskal's Algorithm is used to construct MST, and algorithms are generated on R statistical programming software.

3.2.1. MINIMUM SPANNING TREE METHOD

Minimum spanning tree (MST) is a subset connecting all nodes of a graph with the minimum total edge weight.

In this work, edge weights are distances derived from the cross-correlation of cryptocurrency pairs. Therefore, the MST graph is the connection of all currencies in the study with the minimum total distance. A pair having a high correlation will have a very low distance and it will be more likely to be on MST graph if neighbour cryptocurrencies also have low distances with their neighbours. If there is an option having a less total distance without connecting highly correlated pairs, those pairs might not be on MST graph.

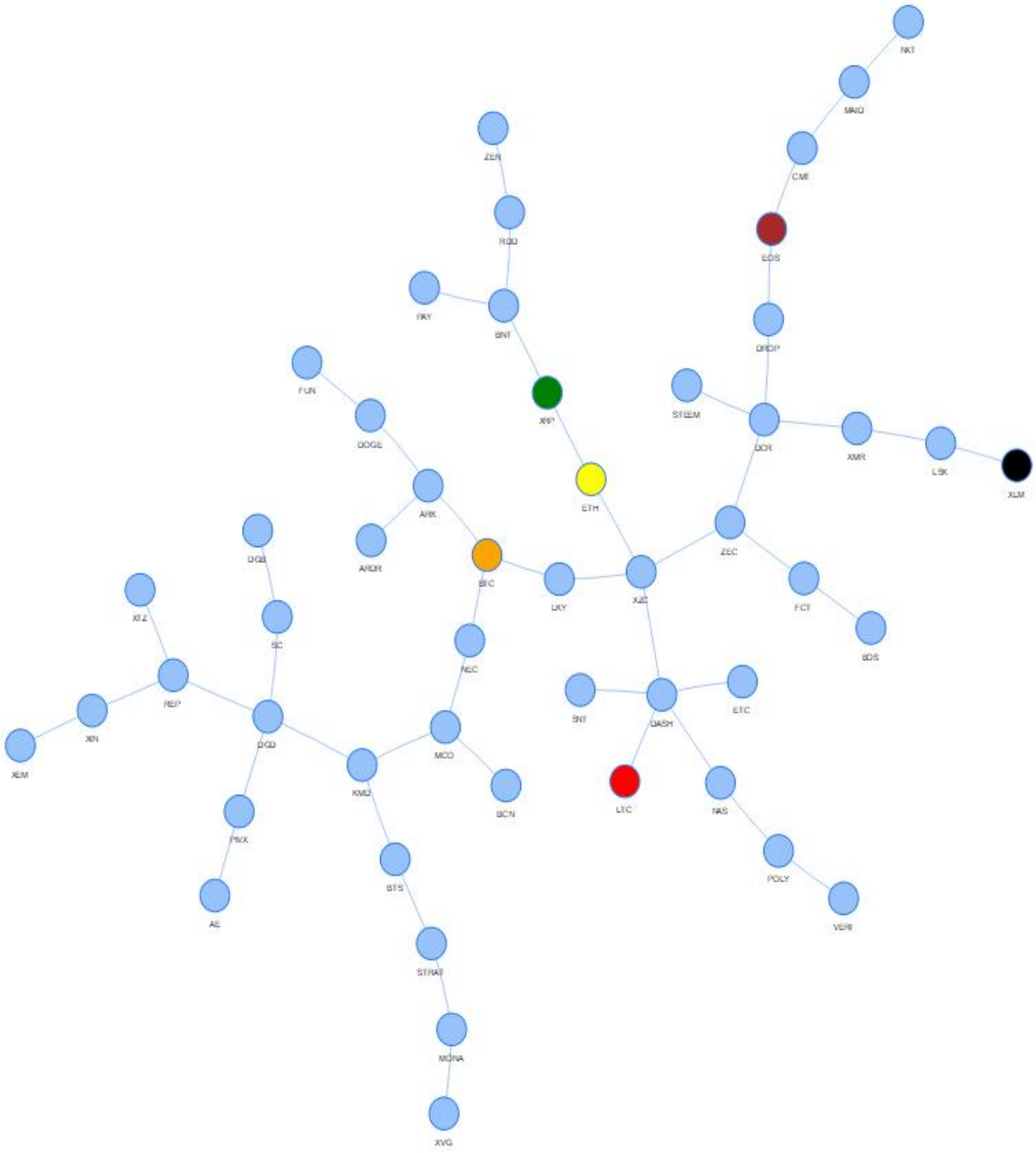


Figure 8. Minimum spanning tree obtained from distance matrix.

In Figure 8, some important currencies with high market cap; such as **BTC** (orange colour), **ETH** (yellow colour), **LTC** (red colour), **XRP** (green colour), **EOS** (brown colour) and **XLM** (black colour) are represented in different colours, while the rest of cryptocurrencies are shown in blue colour. In the graph, it is seen that **BTC** has a central role connecting sub-trees to each other. Other dominant currencies are parts of the sub-trees. For instance, **ETH** and **XRP** are connected to each other which suggests they are highly correlated and therefore have a lower distance.

Currencies which are opposite-correlated with most of the currencies are mostly seen on the outer boundaries of the graph, such as **BOS** and **XLM**.

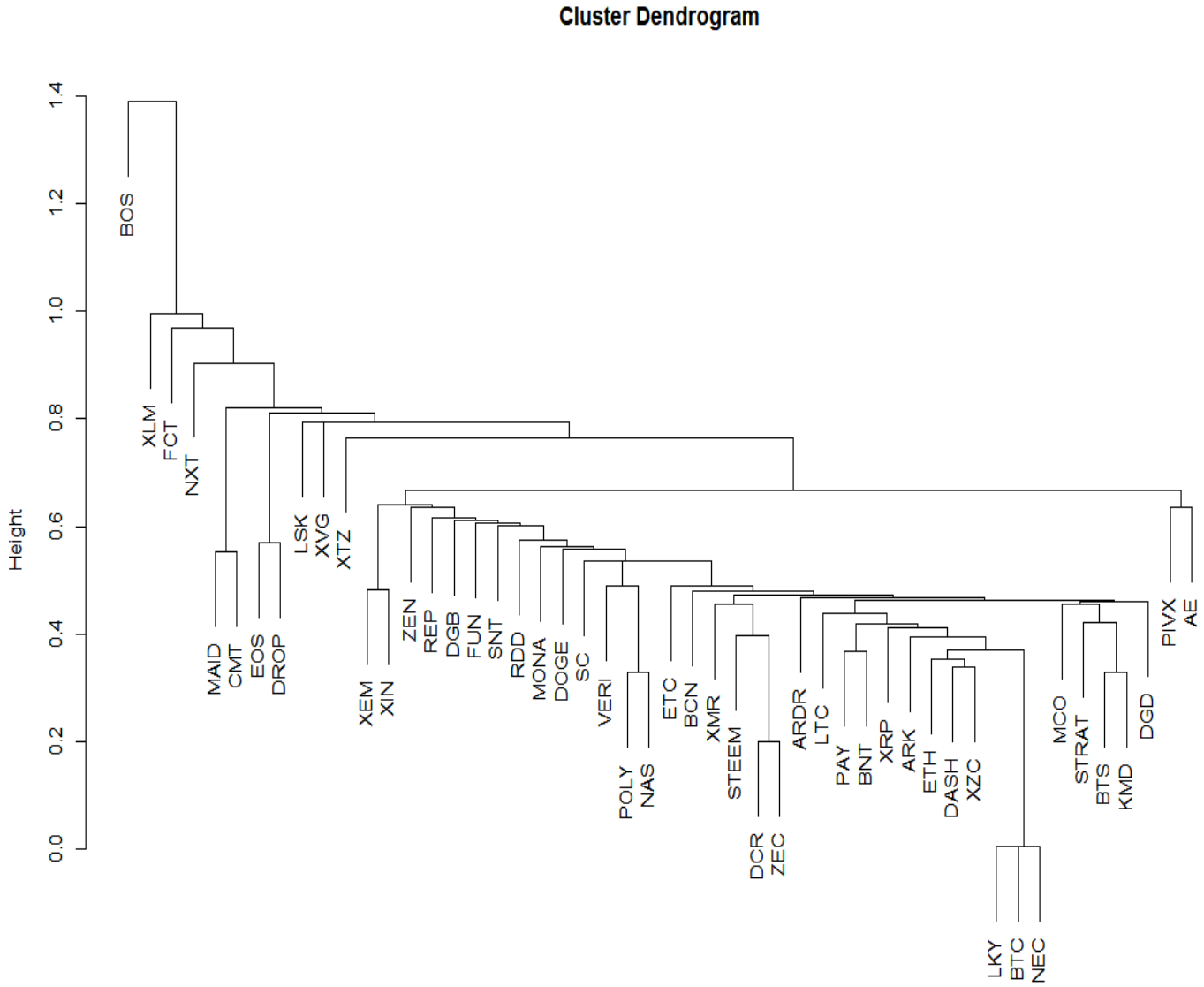


Figure 9. Hierarchical Tree obtained from MST graph.

After obtaining the network of relations with MST method, Hierarchical Tree (HT) method can provide a clustering which may provide sub-trees of cryptocurrencies. In Figure 9, a plot of hierarchical clustering dendrogram is shown. It is shown in the dendrogram that outer currencies in MST graph are the first threshold points to separate if it is to create clusters on the graph. **BOS**, **XLM**, **FCT** and other opposite-correlated currencies are the upper leaves of dendrogram while **BTC**, **LKY**, **NEC** and other highly-correlated currencies are the lowest leaves of the clustering tree.

Having created Hierarchical Tree from MST graph, a further step is to create clusters with respect to hierarchies in the tree. After some inspections, it is decided to create 9 clusters which are represented with distinct colours in Figure 10.

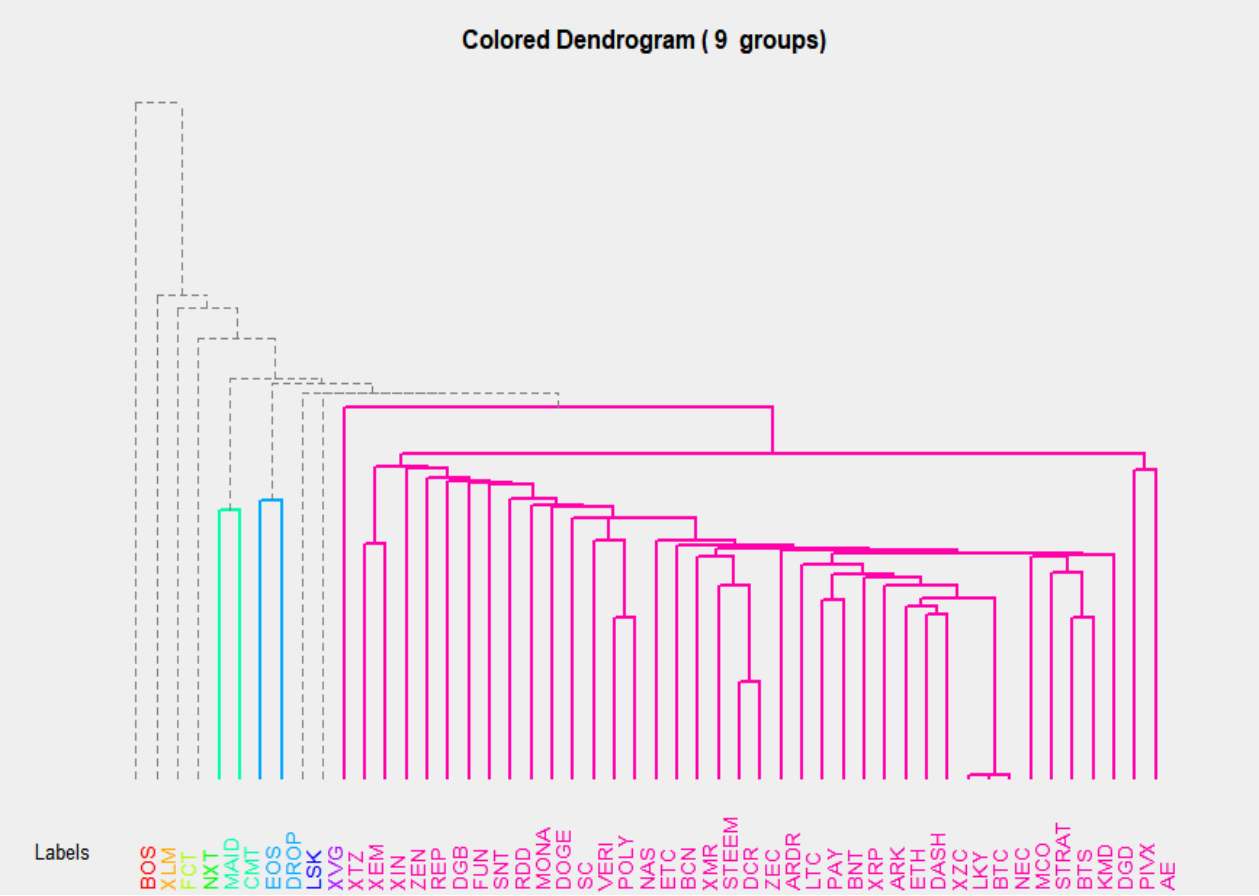


Figure 10. Hierarchical clusters obtained from HST method.

As the number of clusters increases, the outer leaves of the biggest cluster is separated as another cluster. For example, BOS is the outermost leaf of the hierarchical tree and it is to the first cluster generated from the tree. However, sometimes some cryptocoins such as **MAID** and **CMT** or **EOS** and **DROP** are sub-trees of upper leaves and they are together a cluster when they were to be separated from the tree. **BTC**, **LKY** and **NEC** are the lowest levels of hierarchy, therefore they are centre of the biggest cluster in the hierarchical tree.

4. RESULTS AND DISCUSSION

In this part, we introduce the MSTs and the HTs using groups of 50 major cryptocurrencies. A number of investigations about the engaged connections between the currencies can be carried out by analysing the MSTs and their HTs (Ulusoy et al., 2012). This research has a unique feature in terms of combining Minimum Spanning Tree (MST) and Hierarchical Clustering. It is seen that **BTC** has an important and central role in the cryptocurrency network. Also, the relationship between altcoins are examined and sub-trees are generated from MST graph and cluster dendrogram. The outputs of the study prove that some pairs of currencies are highly-correlated; such as **BTC** and **LKY**, while some other pairs of currencies are uncorrelated such as **ETH** and **XLM** or opposite-correlated such as **BOS** and **CMT**.

By investigating these relationships in more detail, outputs of the work may provide insight about future trends of price changes with respect to the latest price changes and its relationship network. Since the popularity of cryptocurrencies are rising, the detected

hierarchical structure derived from this study might be an input for investors and it can be used for further financial studies.

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