Dominant Cryptocurrencies:

A complex networks approach

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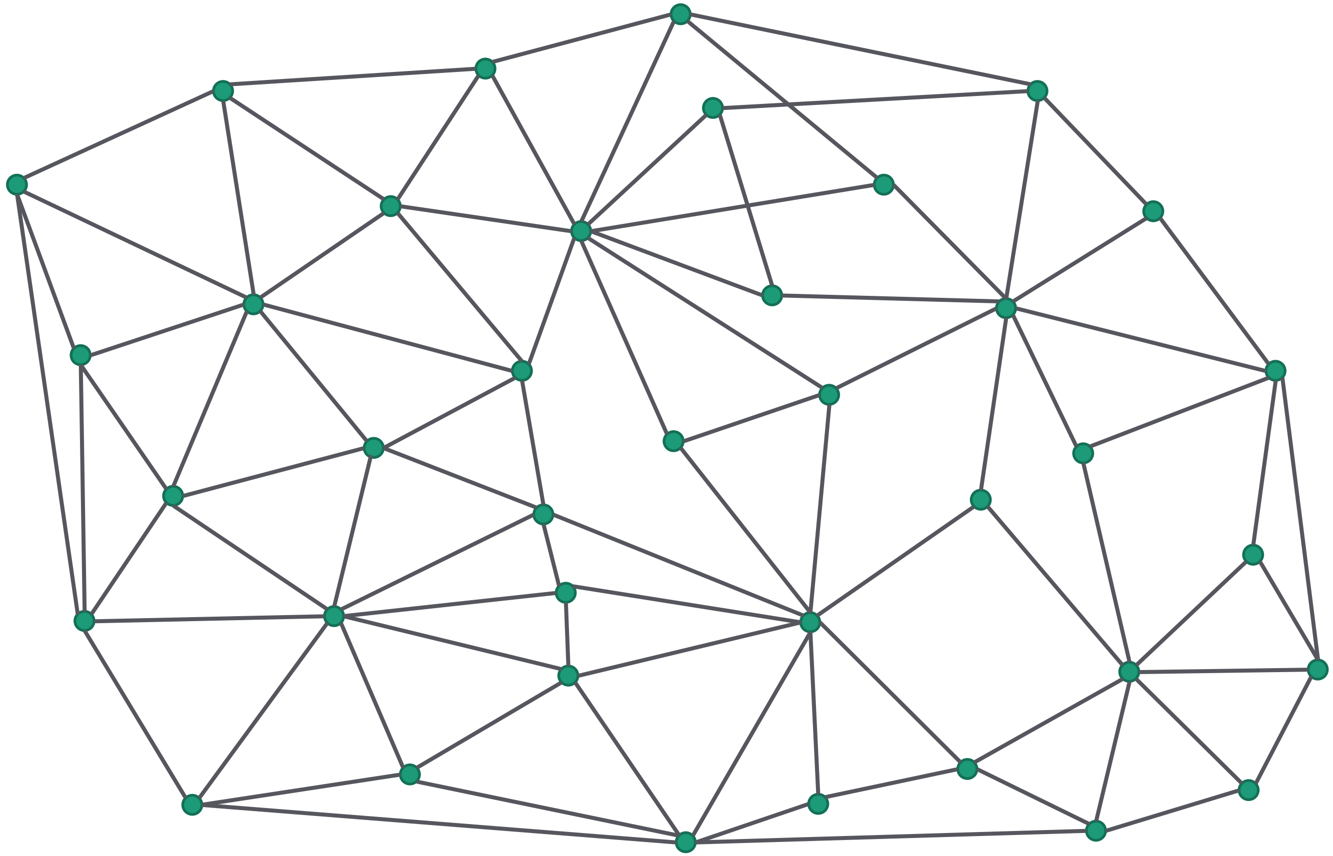
Applications of Complex Networks in Economics

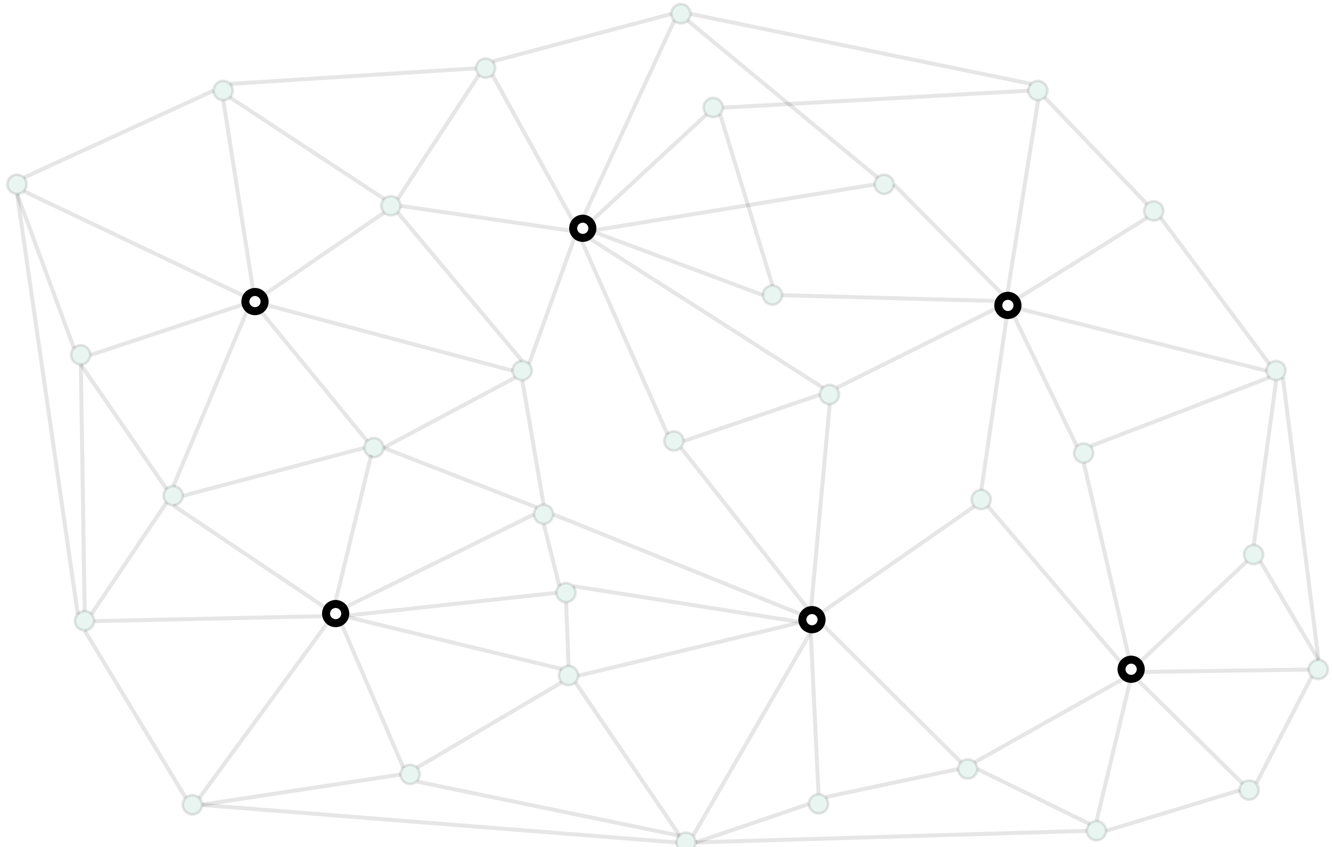
- **Banking Networks Monitoring**
- **Crisis Dispersion**
- **Fraud Detection**

Representation



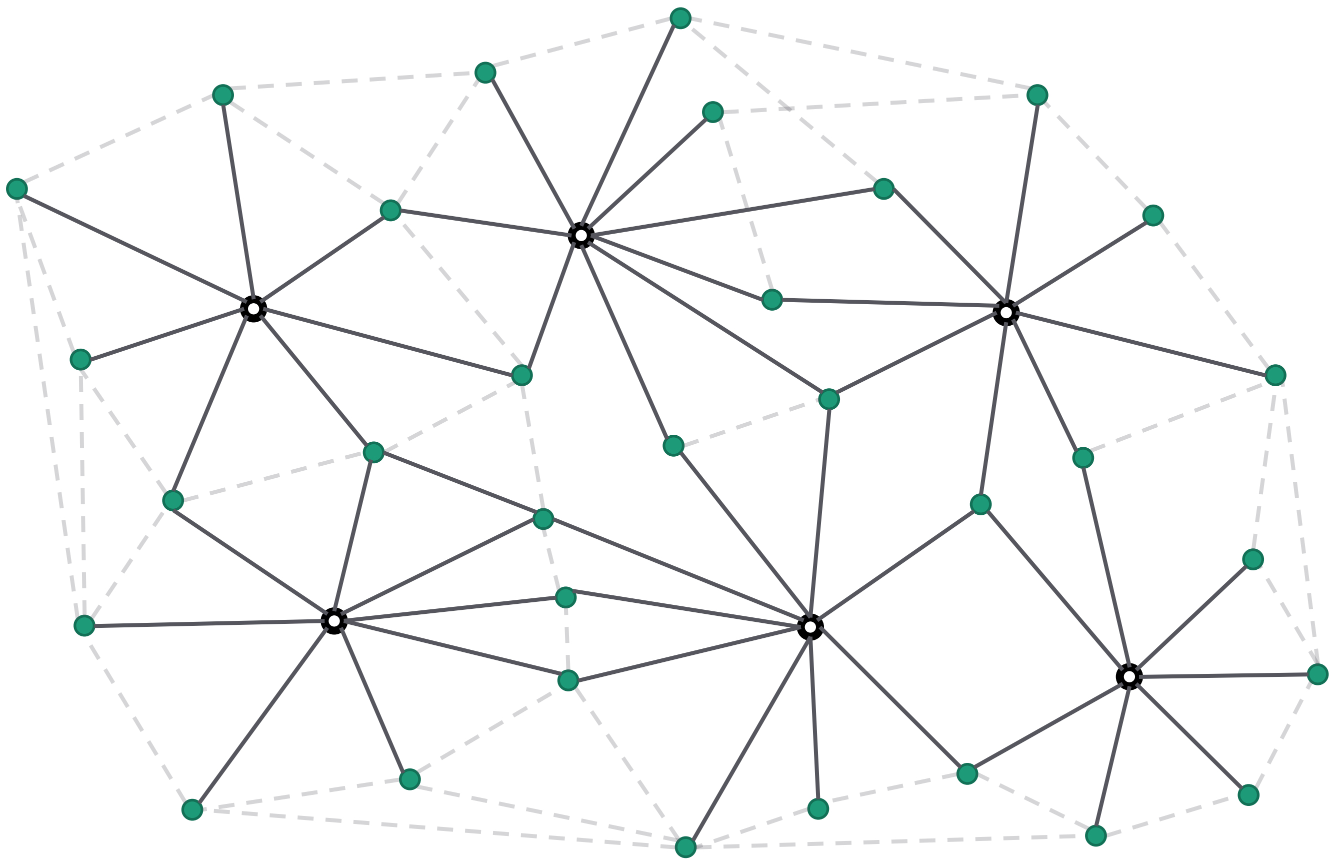
An economic network with nodes connected with edges

Representation



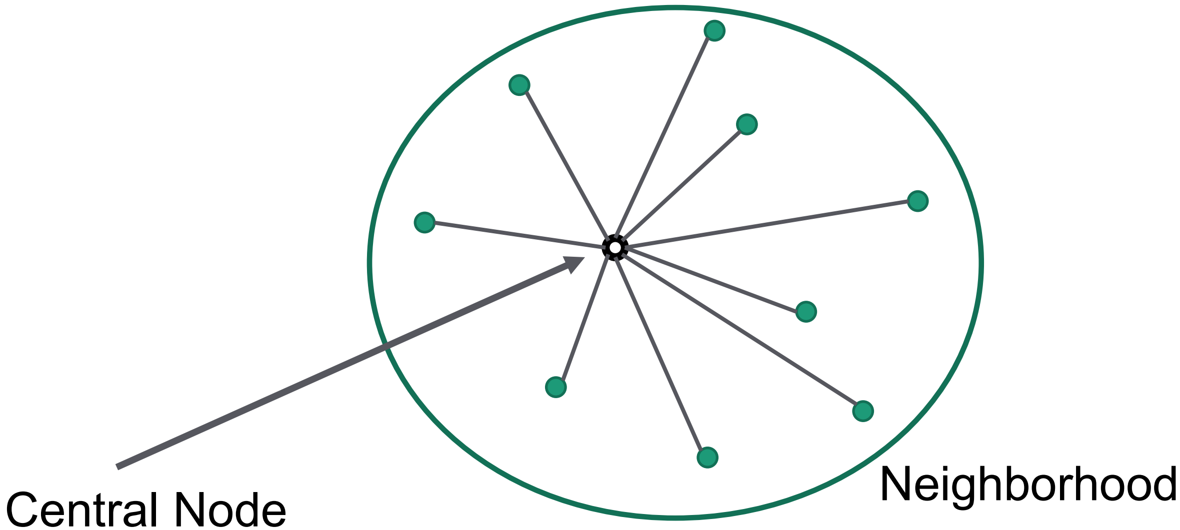
Dominant nodes used for representing the whole network

Representation



Network representation and monitoring by dominant nodes

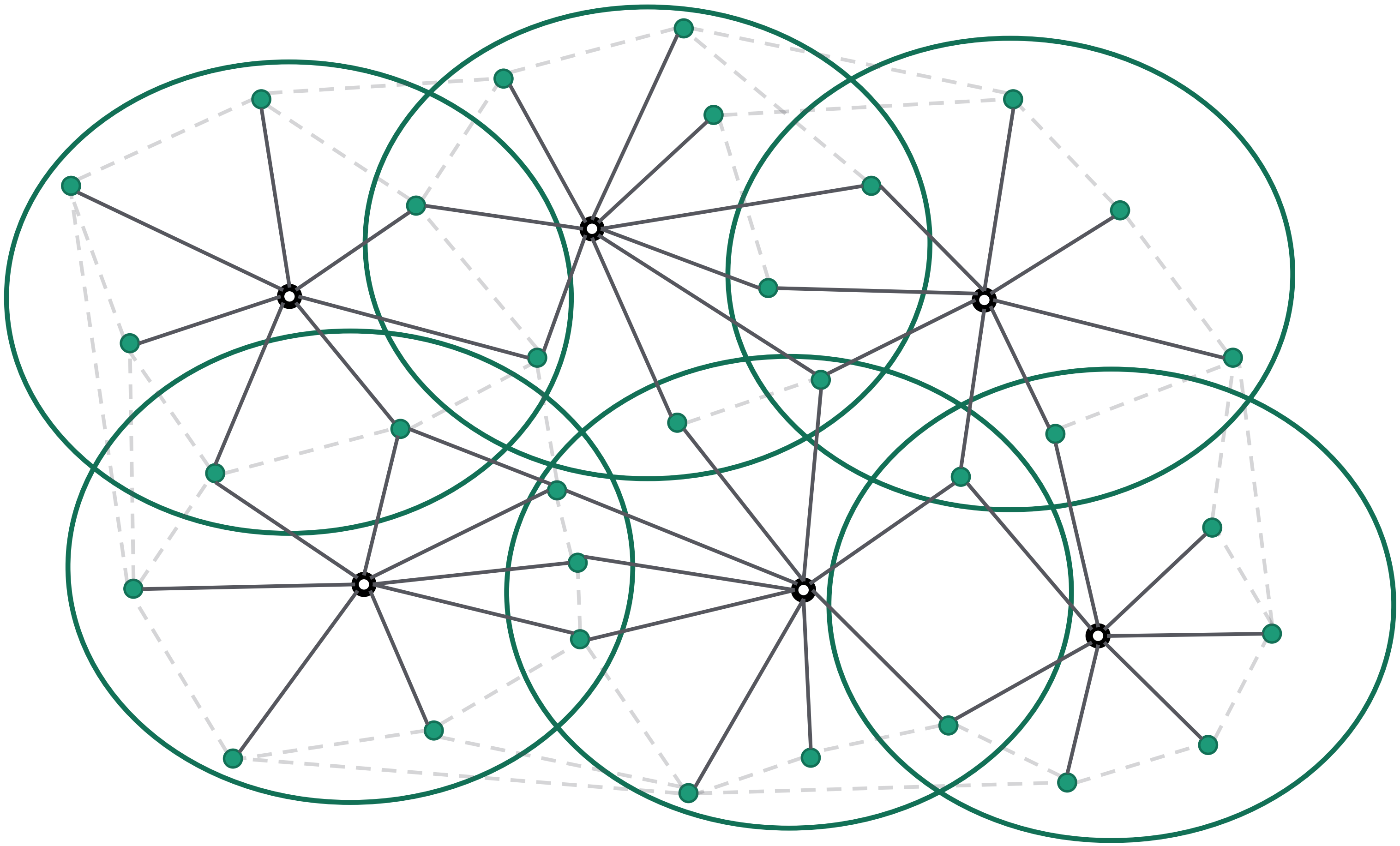
Representation



Dominant Node

Dominant nodes define neighborhoods

Representation



Dominant Nodes, Neighborhoods, Nodes

Approaches Used in Economics Networks

Minimum Spanning Tree (MST)

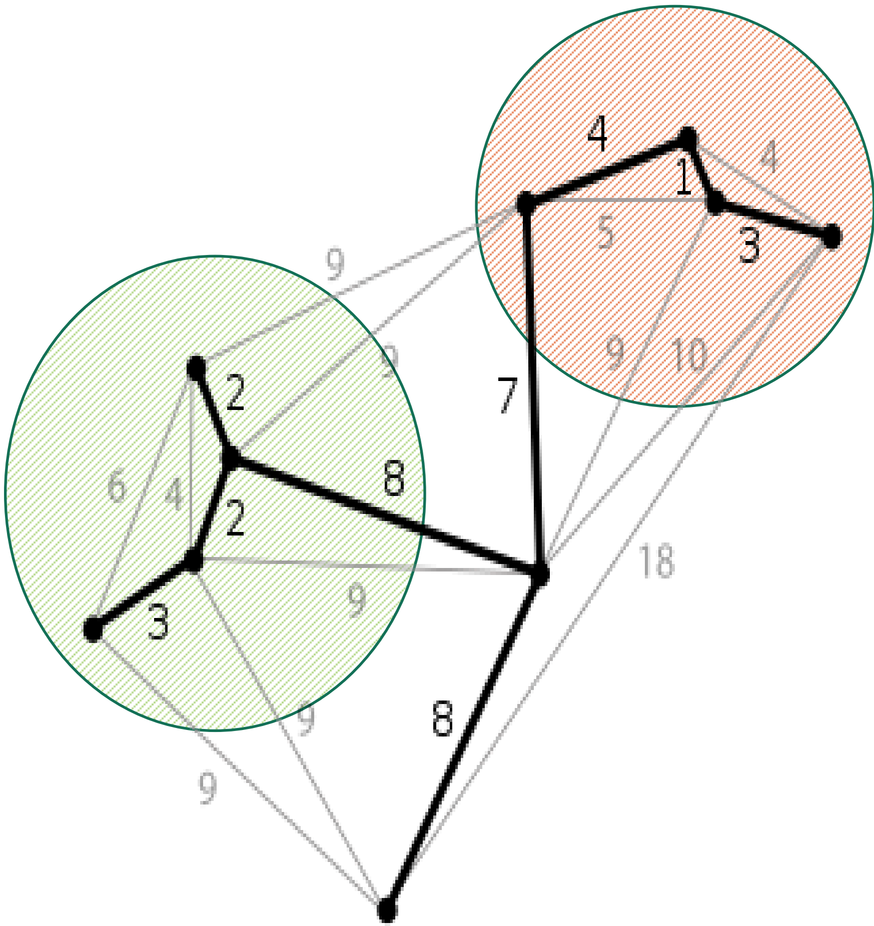
- An **MST** is a subset of the edges of a connected, edge-weighted undirected graph that connects all the vertices together, without any cycles and with the minimum possible total edge weight.

Minimum Dominating Set (MDS)

- AN MDS is a subset D of the nodes such that every node not in D is adjacent to at least one member of D.

MST Solution

- **MST** is widely used in the literature.
- Edges carry "**distances**" to **nodes**.
- Finds the **minimum distance** path connecting **all** nodes.
- **No loops** allowed (closed circuits).
- The central nodes are connected to all others in the network.
- **Neighborhoods**, groups of nodes that are similar.
- From electricity grid, communication, internet networks.
- I.e. Shortest grid to connect households to electricity, water, phone or internet.



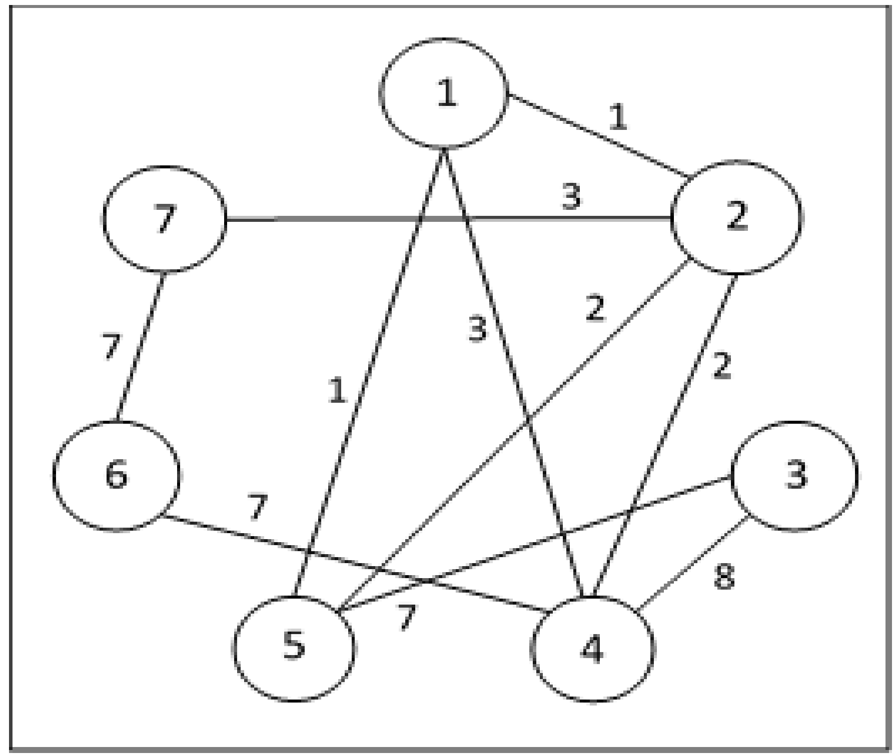
MST Solution (issues)

Example

- An economic network with 7 nodes based on cross-correlations.
- Calculate correlations $\boldsymbol{\rho_{ij}}$ for all nodes.
- Convert correlations to distances $\mathbf{d_{ij} = |\rho_{ij}-1|}$
- The larger the distance the greater the dissimilarity

Goal

- Find representative nodes
- Supervise the whole network using the minimum number of nodes



MST Solution (issues)

Algorithm 1 – Kruskal

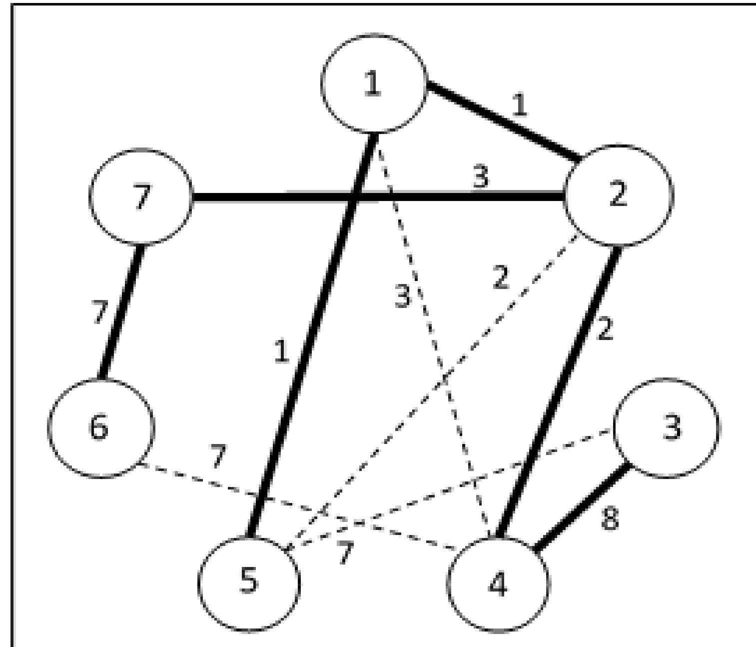
Initialization: Sort the edges in ascending order according to their distance.

Step 1. Select the edge with minimum distance.

Step 2. If the selected edge creates a loop in the path, drop it from the edge list and go to Step 1.

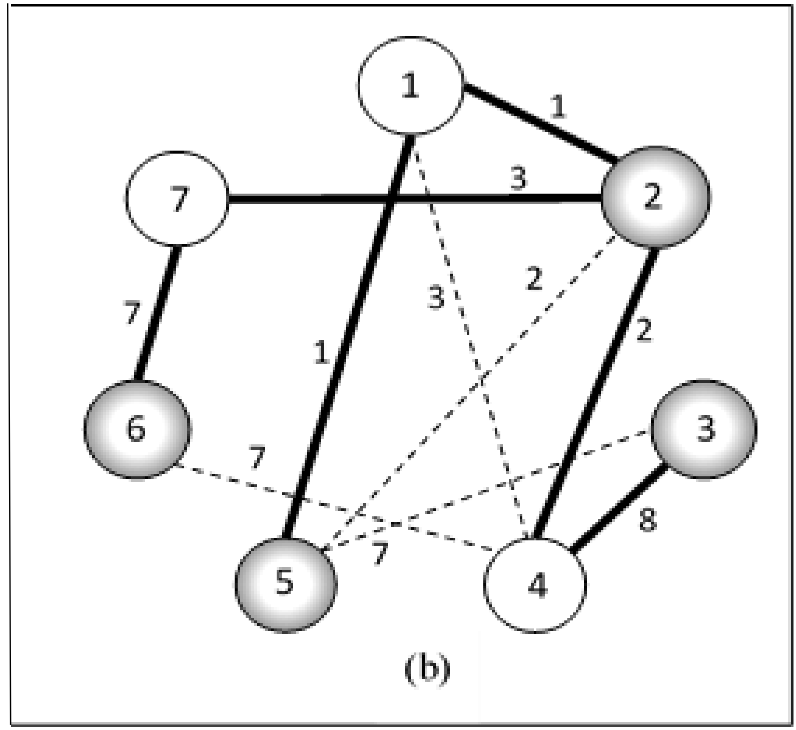
Step 3. Add the selected edge to the MST set and remove the edge from the list.

Step 4. Repeat until all the nodes are connected.



(a)

MST Solution (issues)



Algorithm 2 – Papadimitriou and Gogas

Step 1. Find node m ∈ N: $b_m = \max_i\{b_i\}$ (the maximum degree node)

Step 2. Remove the node m from the network:

Set $b_m = 0$

Step 3. Adjust the degrees of the neighboring nodes:

$\forall$ j ∈ B_m, set $b_j = b_j - 1$

Step 4. Update the core nodes' set

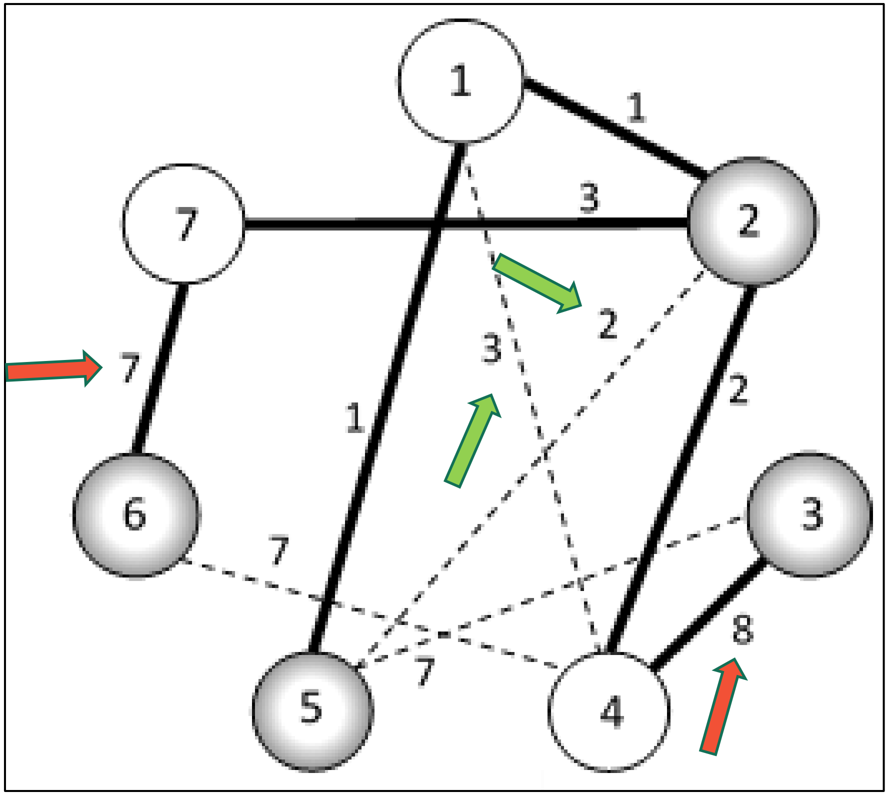
Set $M = M \cup \{m\}$

$\forall$ j ∈ B_m, set $M = M \cup \{j\}$ (the nodes in the neighborhood of m are represented through core node m)

Step 5. Repeat until all the nodes are represented (M = N)

MST Solution (issues)

- Edges with **high distance** survive. Why?
- **No loop** requirement is a **limitation**.
- Serious **problem** with economics networks.



Dominating Set

A subset of nodes in which every node is either

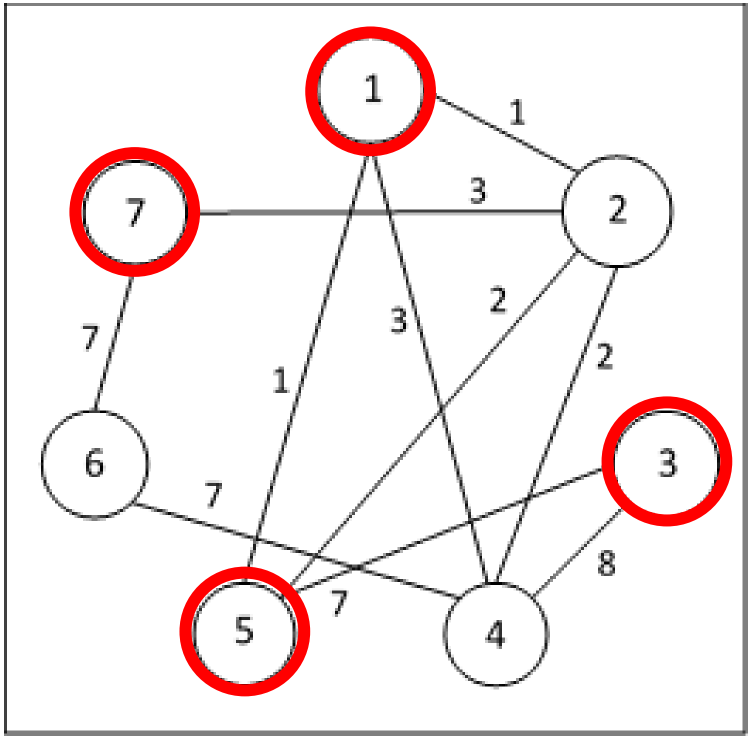
a) a member of the Dominating Set (dominant node)

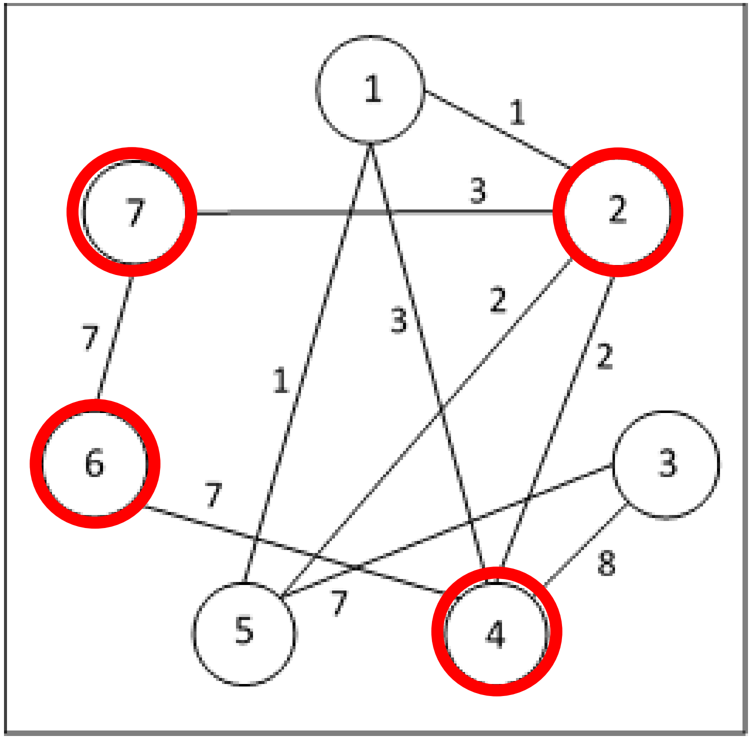
or

b) adjacent to a dominant node

DS Solution

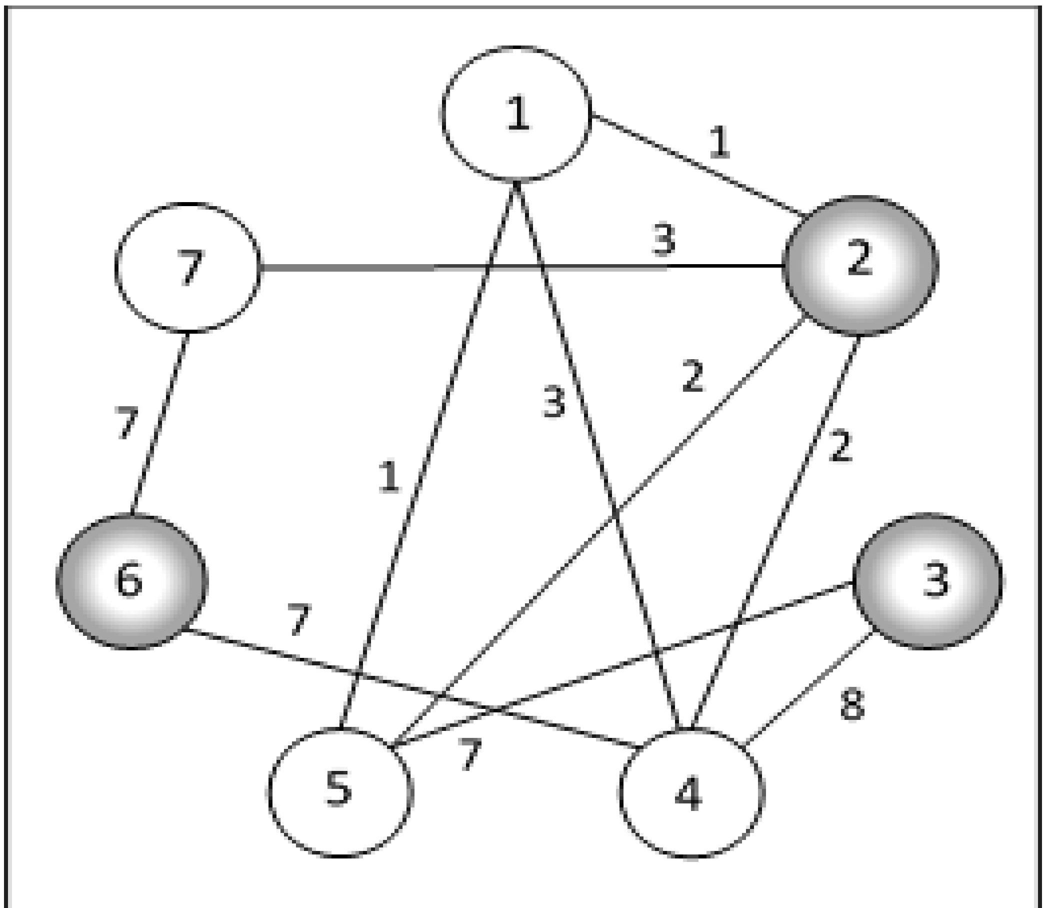
Examples of solutions with Dominant Nodes (in red)





Minimum Dominating Set

The Dominating Set with the minimum cardinality
= Minimum Dominating Nodes



MDS Solution

Membership variable $x_i = \begin{cases} 1 & \text{if node } i \in \text{DS} \\ 0 & \text{if node } i \notin \text{DS} \end{cases} \quad i = 1,2,\ldots,n$

Minimum Cardinality

$$\min_{\mathbf{x}} f(\mathbf{x}) = \sum_{i=1}^{n} x_i \quad \text{subject to}$$

$$x_i + \sum_{j \in \mathrm{B}_i} x_j \geq 1 \qquad i = 1,2,\ldots,n$$

B_i neighborhood of node i

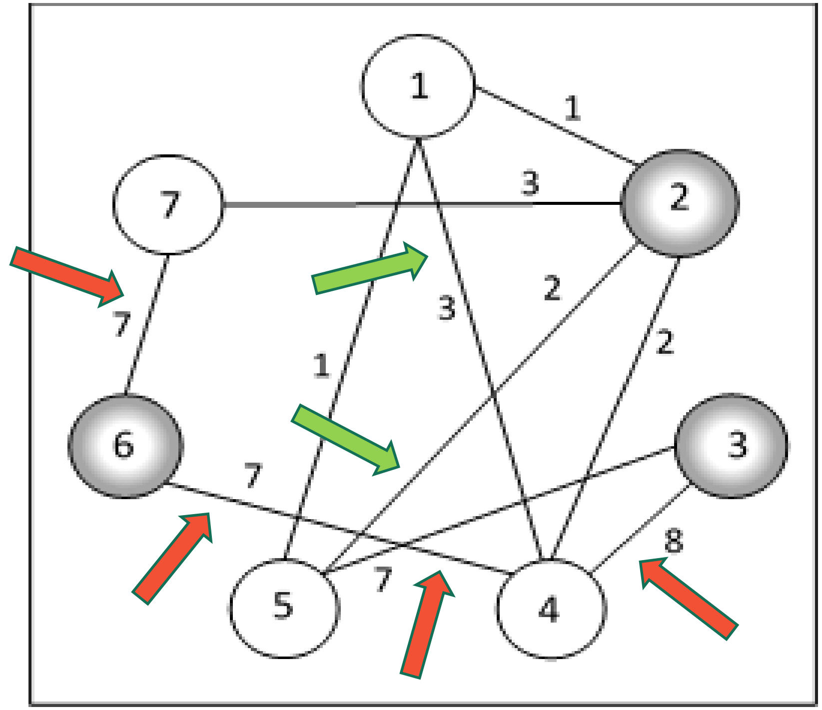
Case 1: $x_i = 1$, i is a Dominant Node

Case 2: $x_i = 0$, some j in the Neighborhood is a Dominant Node

In both cases the left hand side is ≥ 1

MDS Solution comparison

- **3** representative nodes with the **MDS**
- **4** representative nodes with the **MST**
- **MDS** leads to more **compact** representation.
- Edges with useful - relevant information are used in the MDS.
- Nonetheless, edges that appear irrelevant or insignificant are included as well.



Problem!

- Links dissimilar agents together.
- Banks that are healthy with banks in distress.
- Assets that appreciate with others that depreciate in value
- High and low risk assets

This is misleading

Why? It doesn't take into account the distances!

This is misleading because:

- Not all edges are important
- **Emphasis** given on **minimum** representation **not similarity**
- Relates nodes with **dissimilarities – large distances** to produce the MDS.
- **Can be misleading in economics**

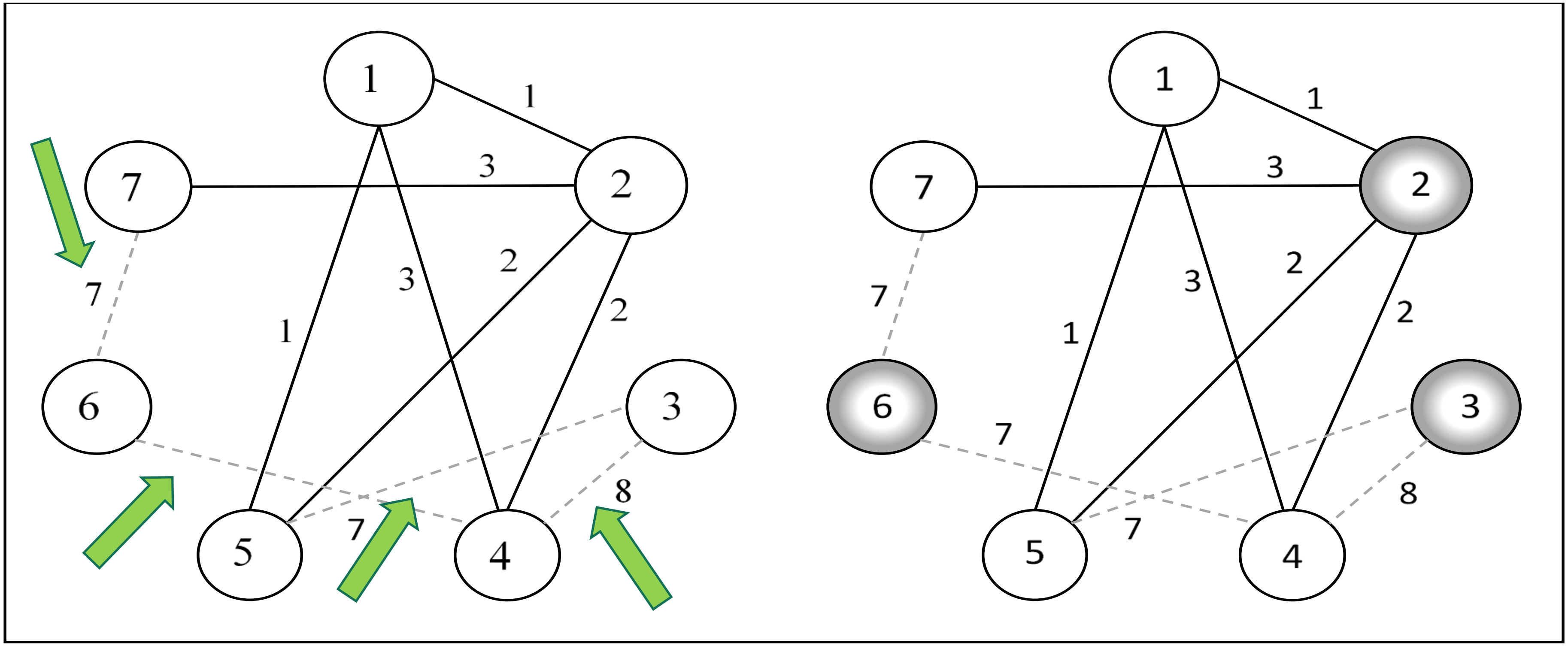
Solution: Gogas-Papadimitriou (2018)
Introduce the Threshold-MDS

Impose a threshold to
remove all uninformative edges

T-MDS Solution

Improve standard MDS

- Apply a **threshold** in the initial network
- **Remove** uninformative nodes
- Find the **MDS** after the thresholding step



T-MDS Solution

Isolated Nodes

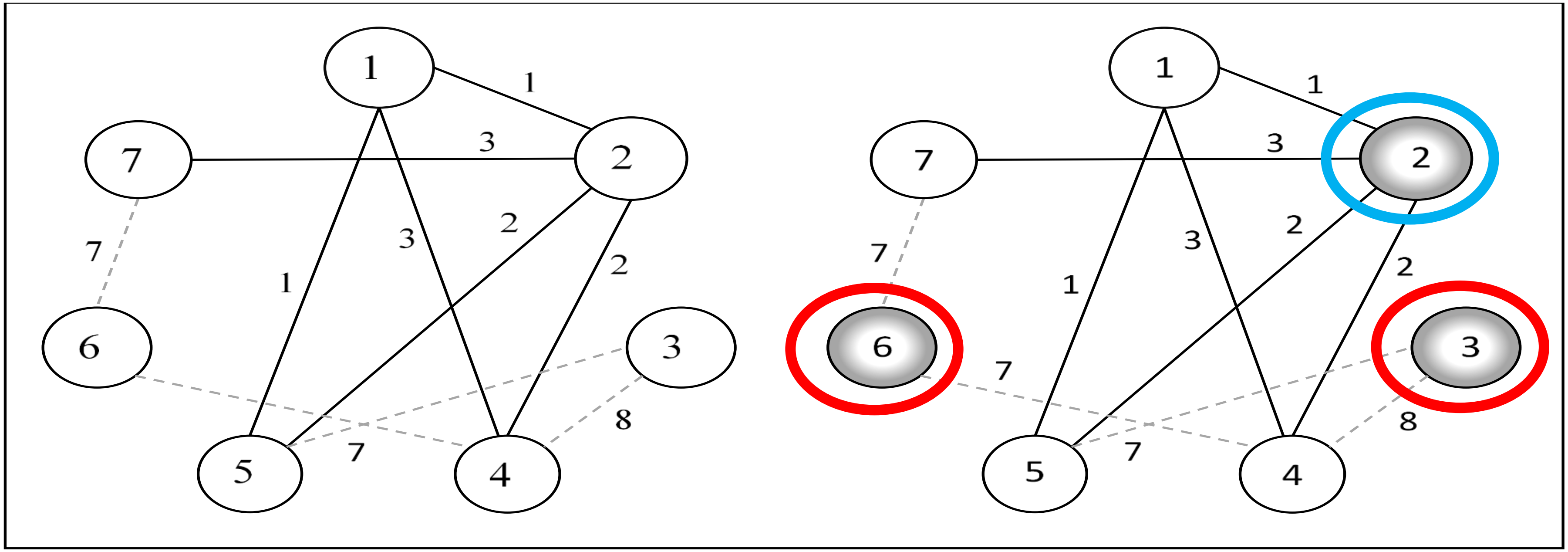
- Creates isolated nodes with no edges to other nodes.
- We study them independently as they represent idiosyncratic behavior.
- Being isolated is important by itself.

Representative Nodes

- MDS nodes belong in the interconnected part of the network.

The T-MDS

- Creates a more reliable representation of the network.
- The DS includes Dominant and Isolated nodes



Why the T-MDS is better?

1. Avoids the **inherent algorithmic restrictions** of the MST – the **no loop requirement**
2. **Improves** the standard MDS algorithm – **ignores** non **uninformative** edges
3. It is **better suited** to **analyze** and **study economics** networks.

The T-MDS

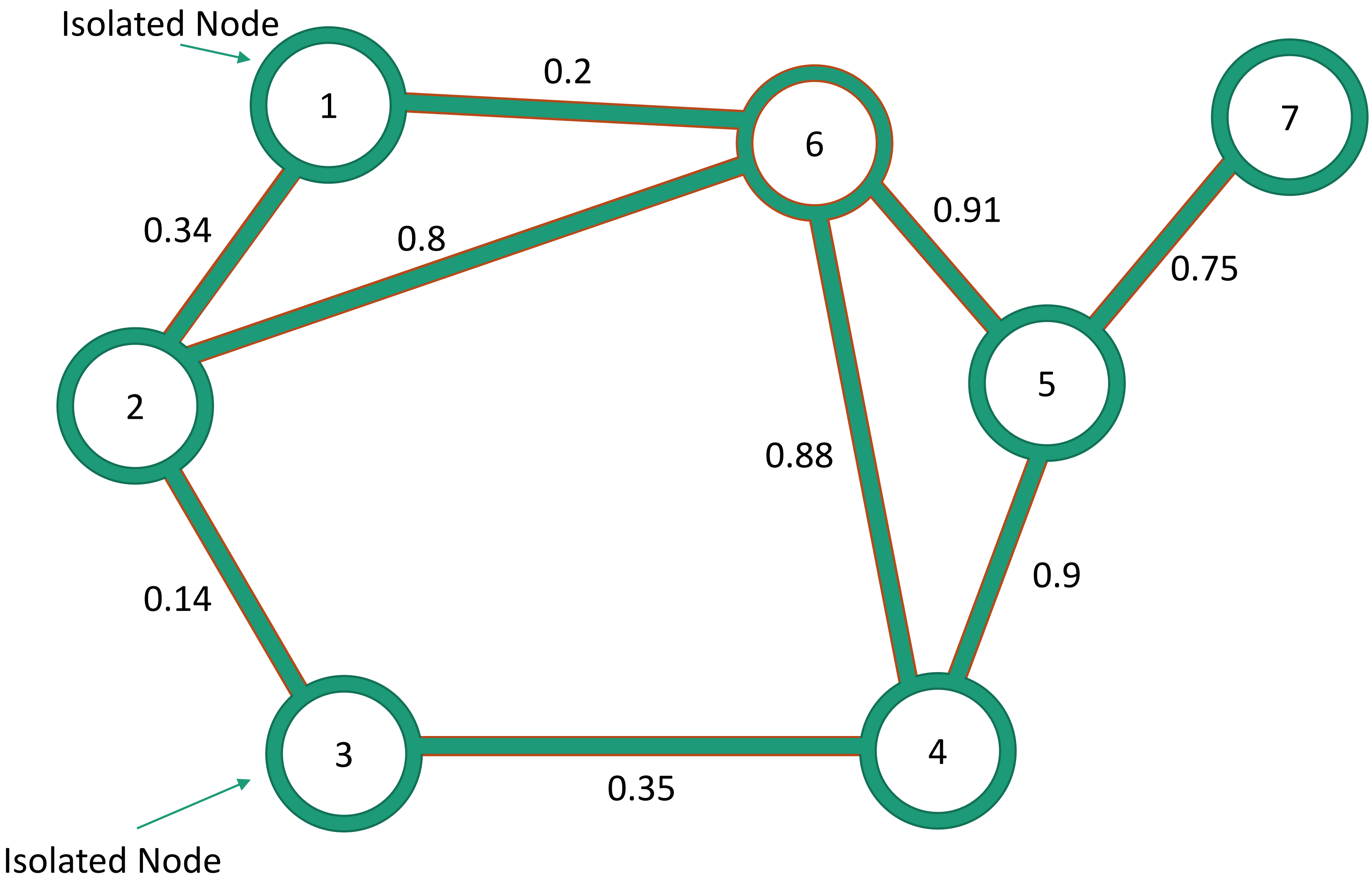
T-MDS is a two step methodology:

1. Threshold imposition on the network
2. Identification of the MDS

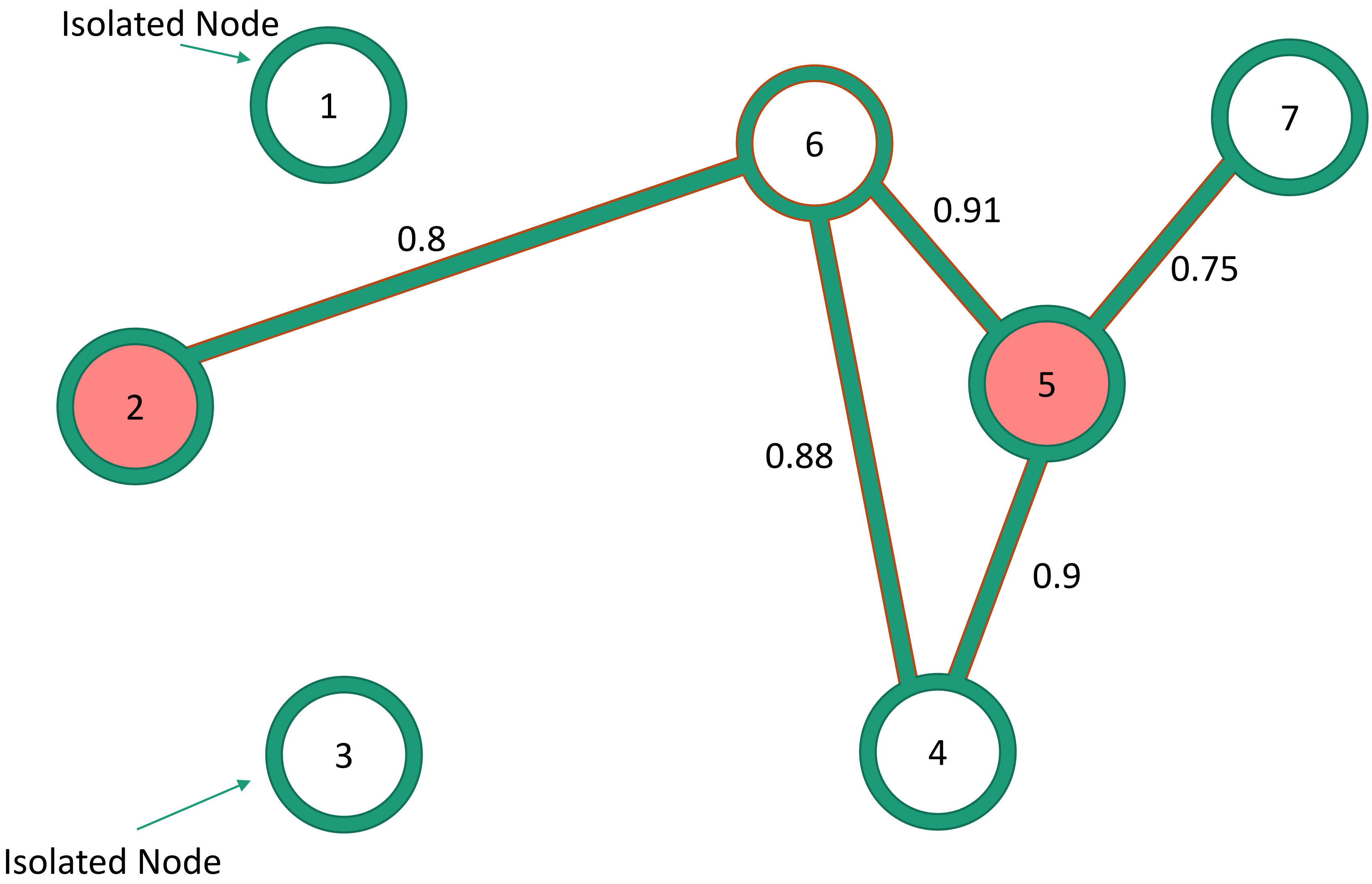
In order to

1. Keep just the essential edges
2. Find the most representative nodes

Threshold = 0.5



Threshold = 0.5

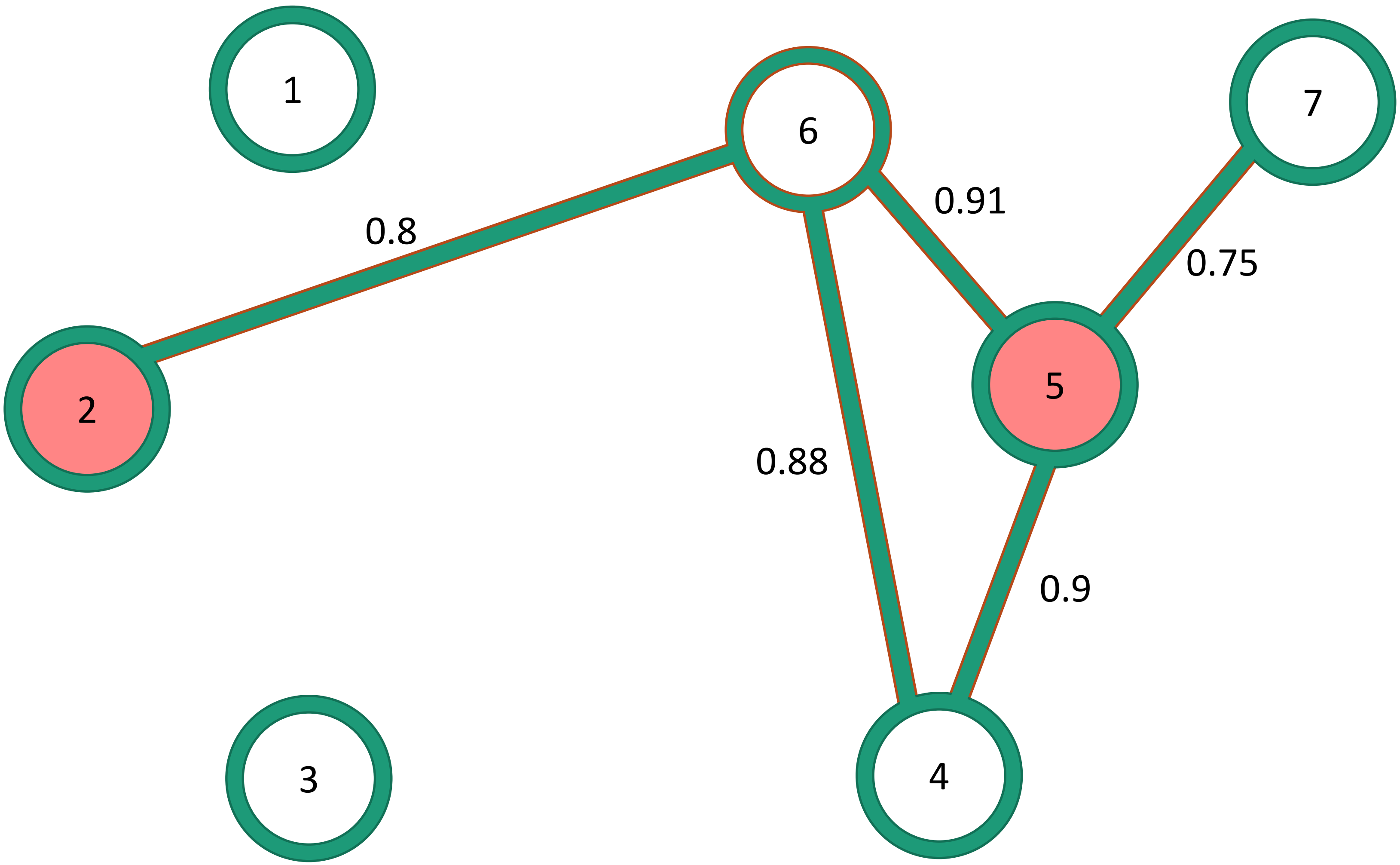


Important Issues

Is there an optimum threshold level?

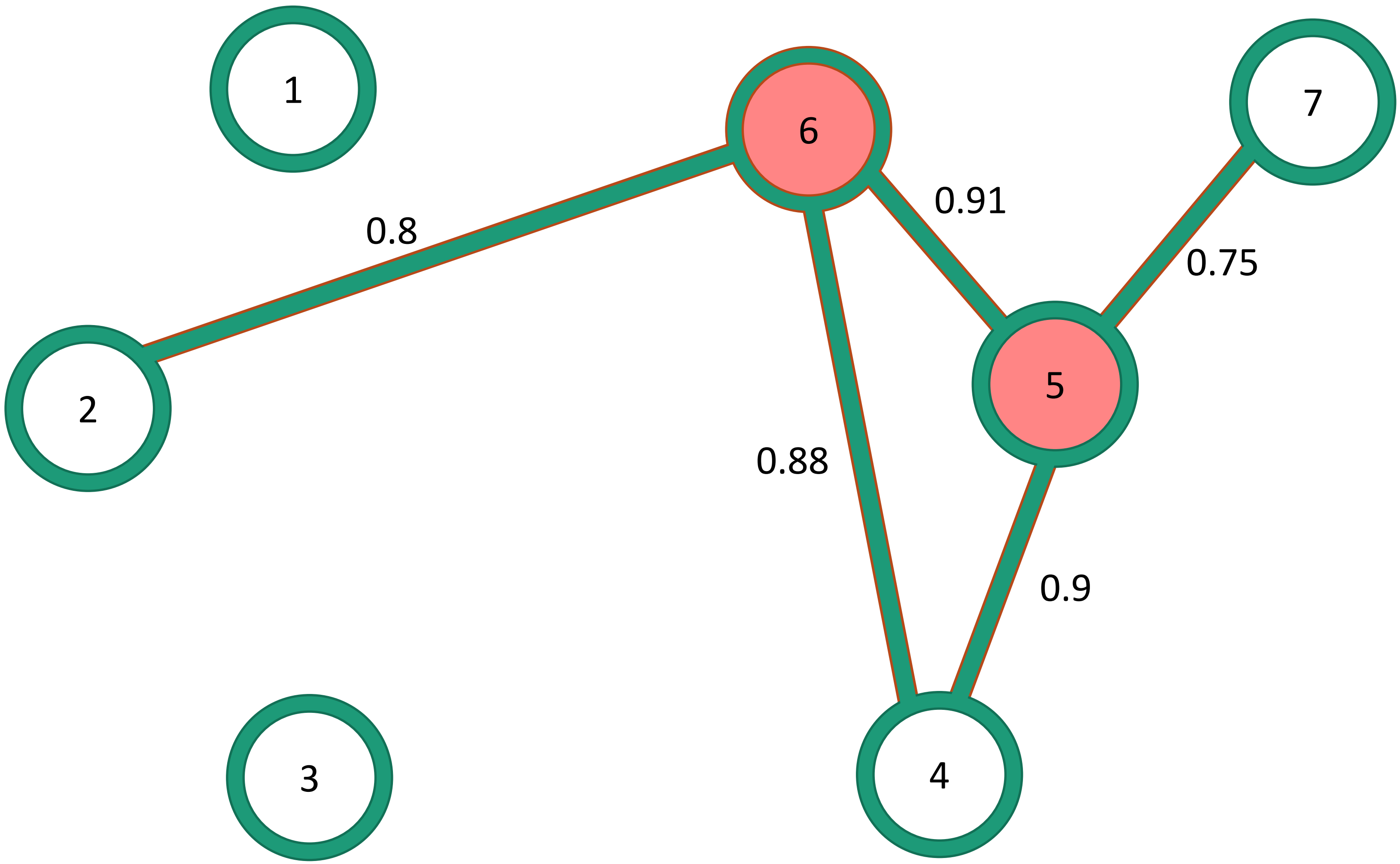
We set it ad hoc depending on the application

This is an MDS. Node 2 and 5



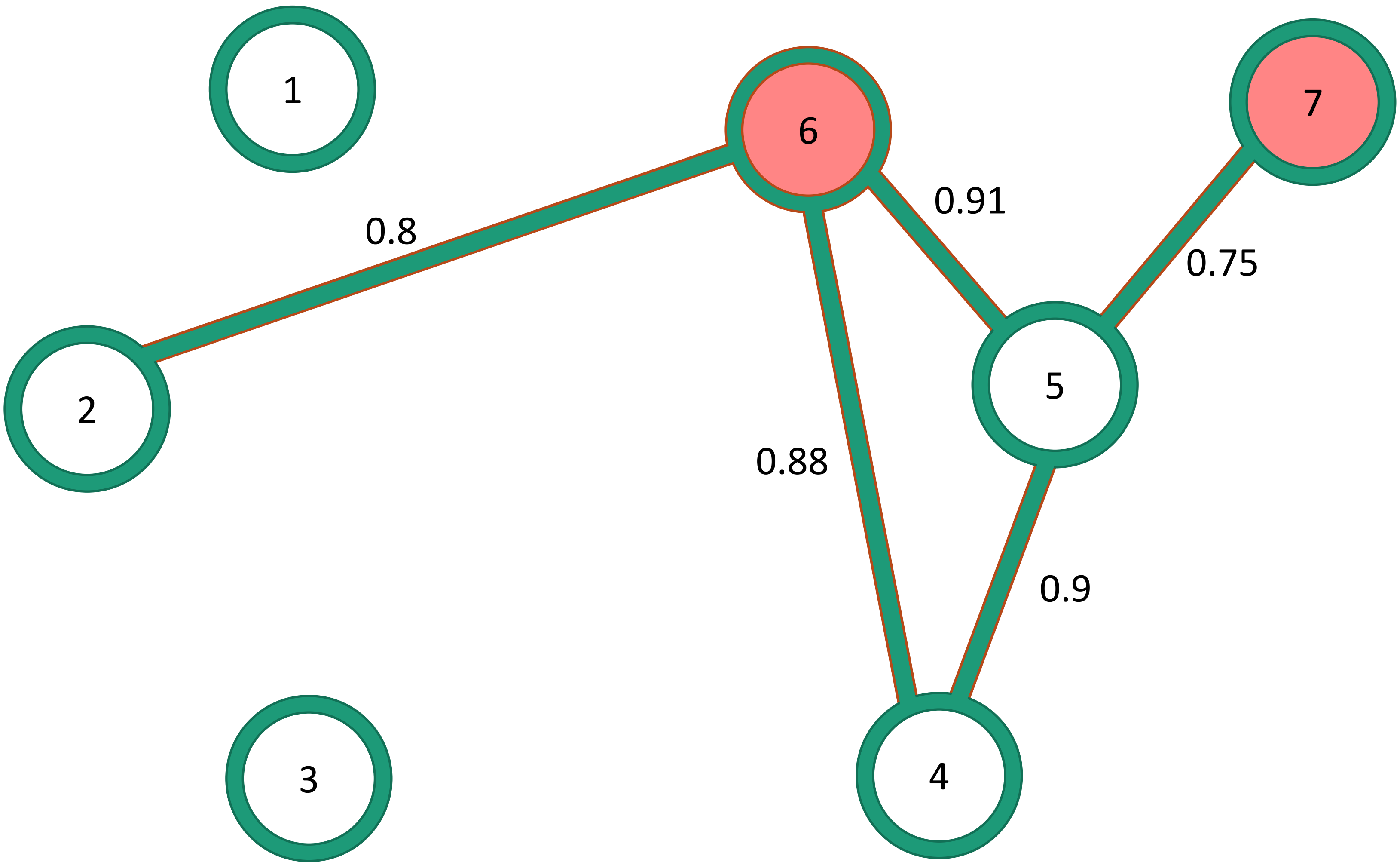
Is T-MDS unique?

This is also an MDS. Node 6 and 5!



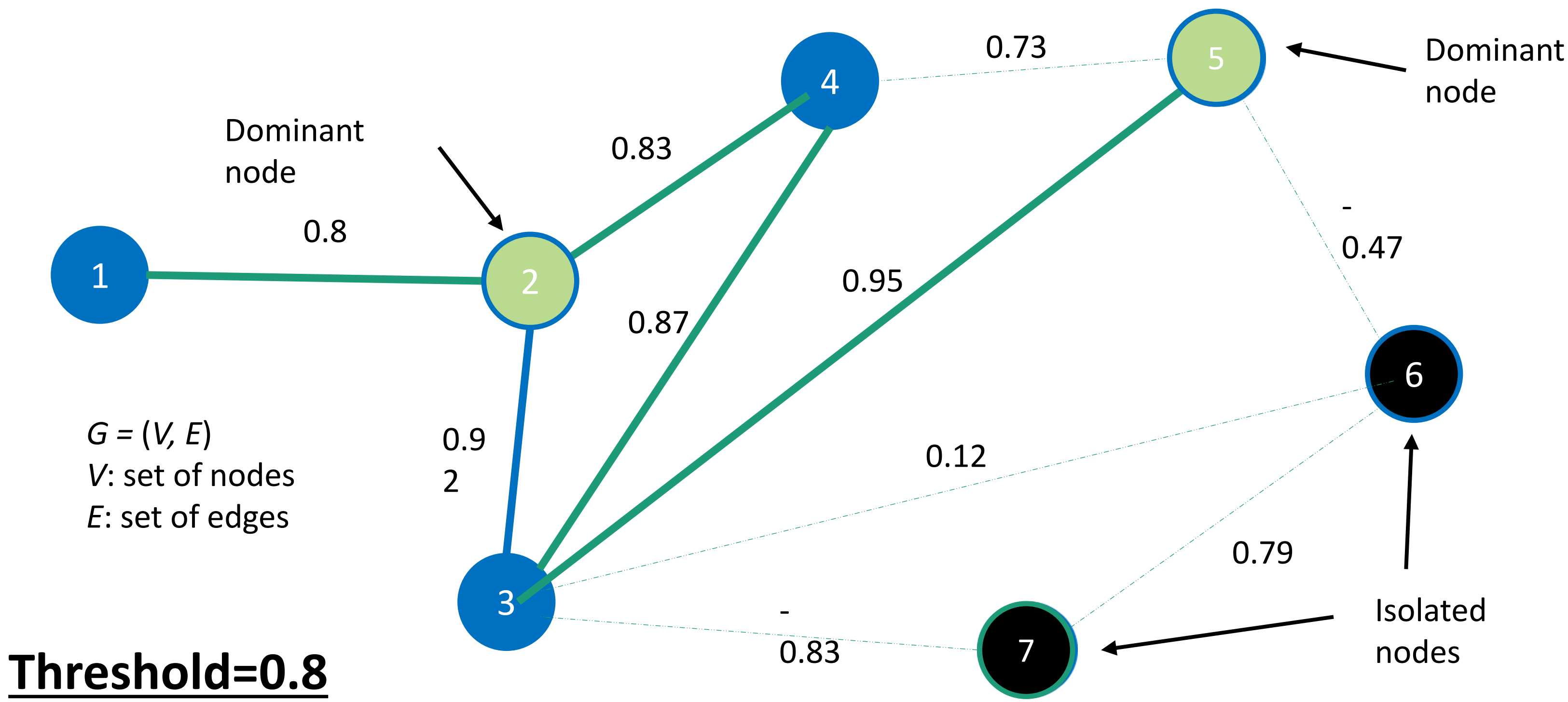
Is T-MDS unique?

And yet another MDS. Node 6 and 7!

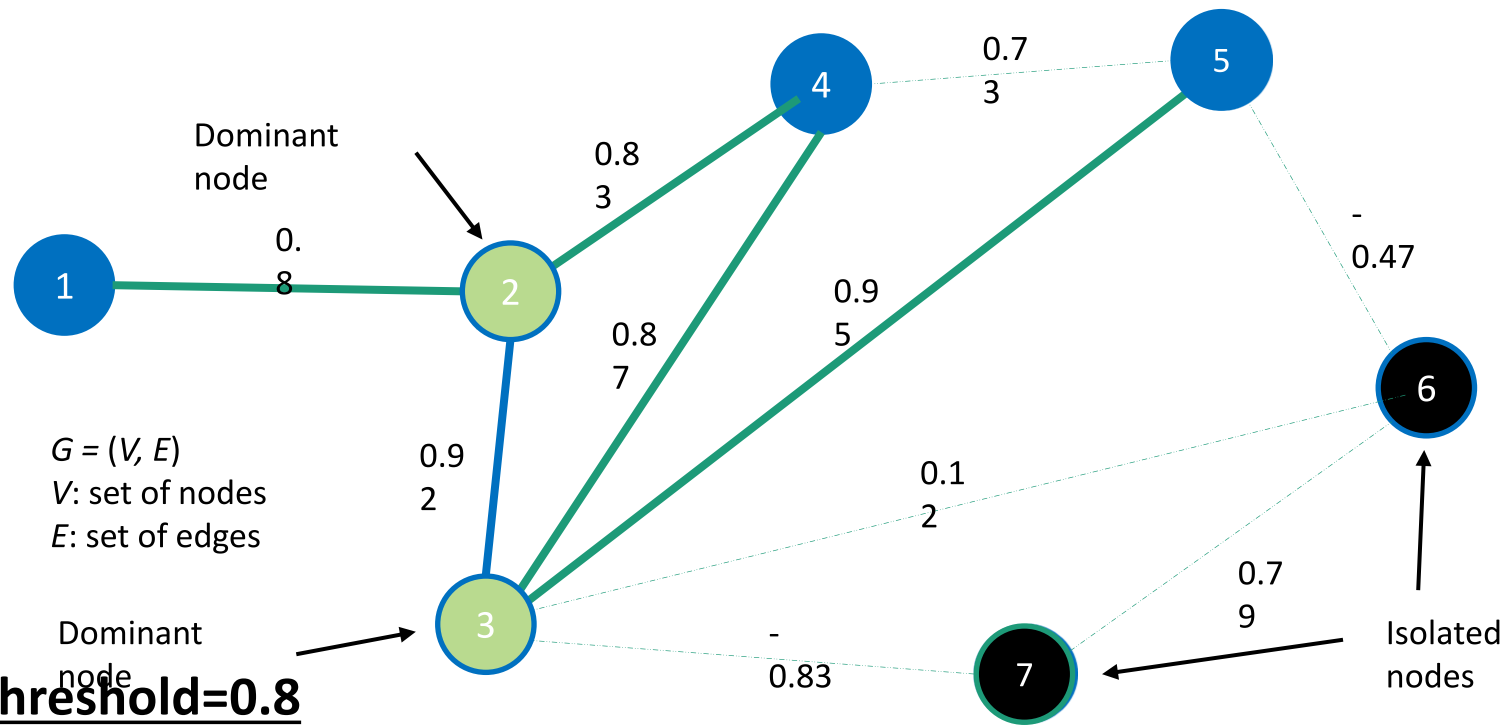


Is T-MDS unique?

Threshold-Minimum Dominating Set

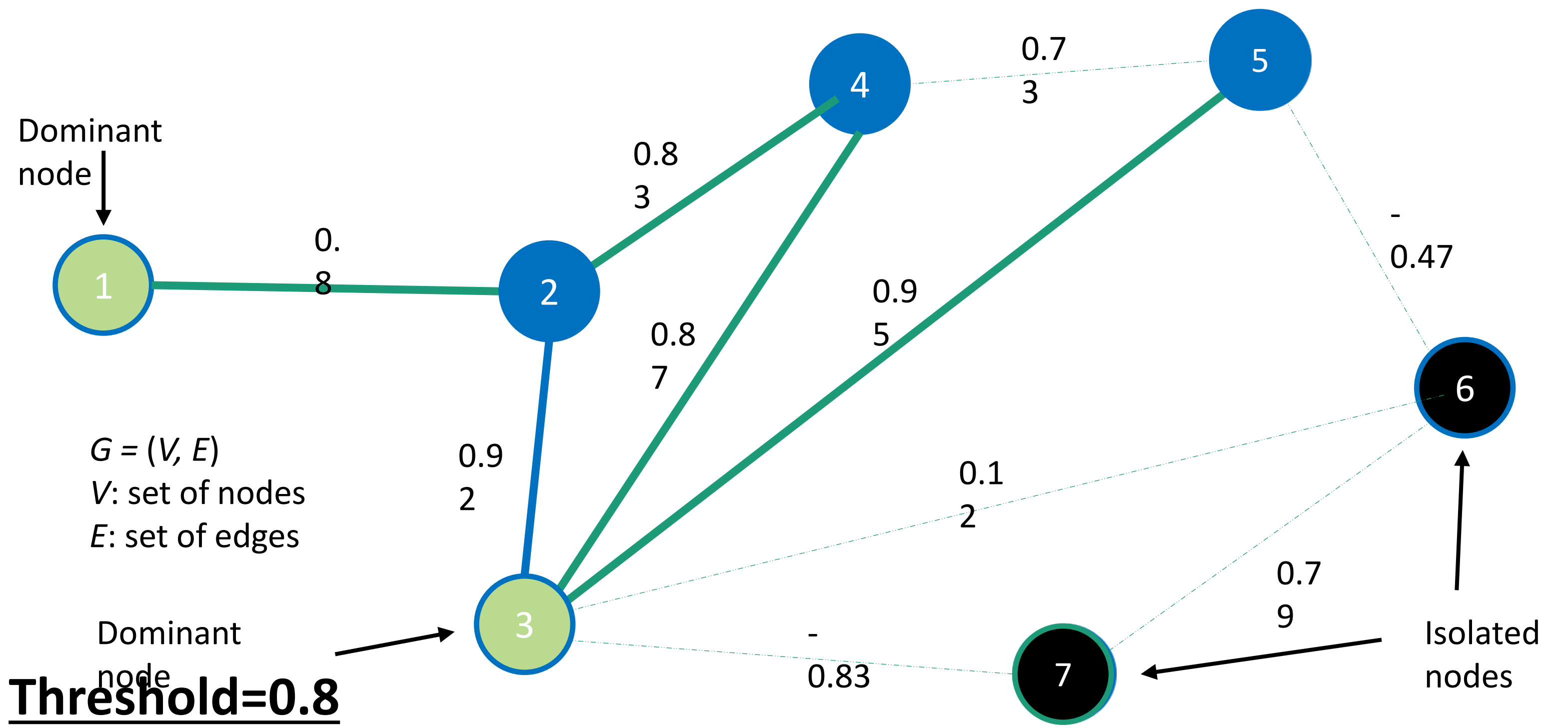


Threshold-Minimum Dominating Set



Threshold=0.8

Threshold-Minimum Dominating Set



Disadvantage for Temporal Analysis

Unable to follow the MDS evolution

MDS may change randomly

Without an economic interpretation

Solution: Gogas and Papadimitriou (2009): the TW-MDS Threshold Weighted - MDS

Impose a Node weight

Node importance: market cap, assets, etc.

$$\min_{\mathbf{x}} f(\mathbf{x}) = \sum_{i=1}^{n} w_i x_i$$

$$x_i + \sum_{j \in \mathrm{B}_i} x_j \geq 1 \qquad i = 1,2,\ldots,n$$

Why the TW-MDS is better?

1. Avoids the inherent **algorithmic restrictions** of the MST – the **no loop** requirement.
2. Improves the standard MDS algorithm – **ignores non informative** edges.
3. Improves **stability** and **interpretability** of the resulting networks with weights.
4. It is **better suited** to analyze and study **economics networks**.

Dominant Cryptocurrencies

Research team: Theophilos Papadimitriou, Periklis Gogas, Fotios Gkatzoglou

THE DATA

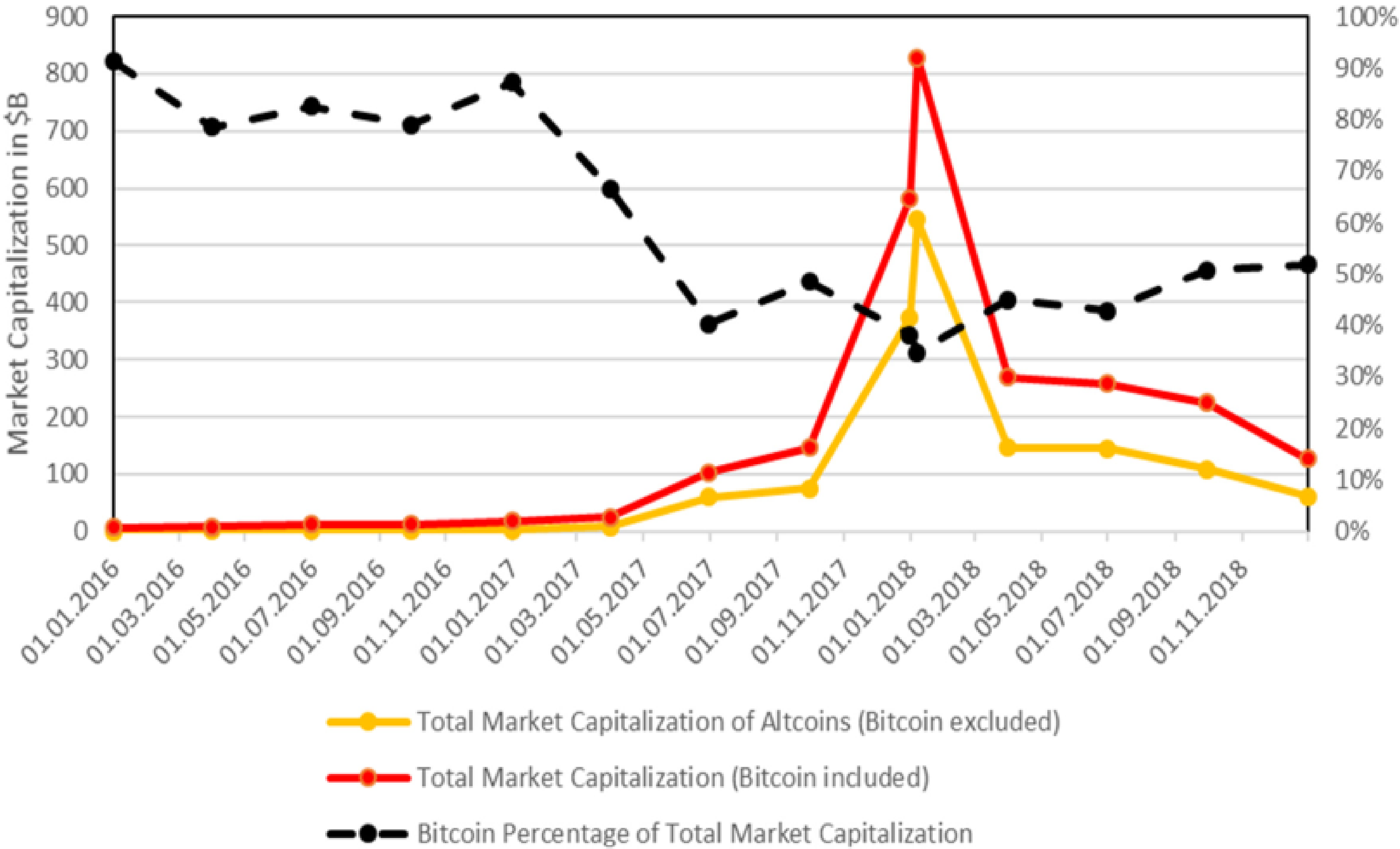
- **112** cryptocurrencies from CoinMarket
- From **01.01.2016** to **31.12.2018**.
- A period that includes a **major peak** in market capitalization: from $7.12 billion to $828.57 billion in 07.01.2018.
- The **Bitcoin's** market **dominance** (i.e. percentage of total market capitalization) steadily **declined** during this period from over 90% to 40%–50%.
- The dataset includes:
  (a) the **six** more important in terms of **capitalization** cryptocurrencies
  (b) 106 **randomly** selected cryptocurrencies from every part of the cryptocurrency capitalization spectrum.
- **Capitalization** of each of the six most important cryptos is **over $1 billion**, while the capitalization of each of the rest **Altcoins** is between **$100 thousand** and **$1 billion** (as of January 2019).
- All cryptocurrencies in the sample were **launched before 2016** and remained **active** for the next three years

Dominant Cryptocurrencies

Table 1
The 112 cryptocurrencies in the dataset, ranked by their market capitalization (descending order) as of January 2019.

1	Bitcoin	29	Blocknet	57	Crown	85	PinkCoin
2	Ethereum	30	Emercoin	58	HempCoin	86	Pura
3	Ripple	31	NavCoin	59	Pandacoin	87	MaxCoin
4	Litecoin	32	Viacoin	60	Bean Cash	88	Bullion
5	Stellar	33	Namecoin	61	SolarCoin	89	Auroracoin
6	Tether	34	Ubiq	62	MonetaryUnit	90	FoldingCoin
7	Monero	35	Gulden	63	Myriad	91	Bitcoin Plus
8	Dash	36	FLO	64	MintCoin	92	FedoraCoin
9	NEM	37	DigitalNote	65	ECC	93	NeosCoin
10	Dogecoin	38	Burst	66	GridCoin	94	Zeitcoin
11	DigiByte	39	BitCNY	67	Sphere	95	Orbitcoin
12	Bytecoin	40	WhiteCoin	68	Dotcoin	96	CannabisCoin
13	BitShares	41	BlackCoin	69	Gambit	97	Pesetacoin
14	Verge	42	BitBay	70	Omni	98	HunterCoin
15	Siacoin	43	GameCredits	71	Circuits of Value	99	Bitmark
16	Factom	44	Counterparty	72	GoldCoin	100	LiteDoge
17	MaidSafeCoin	45	Aeon	73	Curecoin	101	Bitzeny
18	Groestlcoin	46	Primecoin	74	Anoncoin	102	e-Gulden
19	ReddCoin	47	I/O Coin	75	OKCash	103	AudioCoin
20	MonaCoin	48	PotCoin	76	NewYorkCoin	104	DigitalPrice
21	Syscoin	49	Global Curr. Res.	77	BitSend	105	HyperStake
22	Nxt	50	Stealth	78	Capricoin	106	Neutron
23	Nexus	51	Feathercoin	79	Terracoin	107	BunnyCoin
24	Vertcoin	52	FairCoin	80	GCN Coin	108	Canada eCoin
25	Unobtanium	53	Xaurum	81	Novacoin	109	Magi
26	Clams	54	VeriCoin	82	ArtByte	110	SpreadCoin
27	Einsteinium	55	CloakCoin	83	ExclusiveCoin	111	Adzcoin
28	Peercoin	56	Diamond	84	DopeCoin	112	Universal Curr.

Dominant Cryptocurrencies



Dominant Cryptocurrencies

Empirical work

- Create 3 networks, 1 for each year, daily observations
- For the vertices use the Pearson's correlation coefficient $r_{i,j}$

$$r_{i,j} \triangleq \frac{COV\left(Z_i, Z_j\right)}{\sqrt{VAR\left(Z_i\right) VAR\left(Z_j\right)}}$$

- Use thresholds: 0.6, 0.7, 0.8, 0.9.

Dominant Cryptocurrencies

Isolated Nodes – not interconnected part of the network

- Per year
- Per threshold

Table 2
Isolated nodes for various threshold instances.

Isolated nodes			
Threshold	2016	2017	2018
0.6	20	4	2
0.7	33	5	6
0.8	57	8	8
0.9	90	27	14

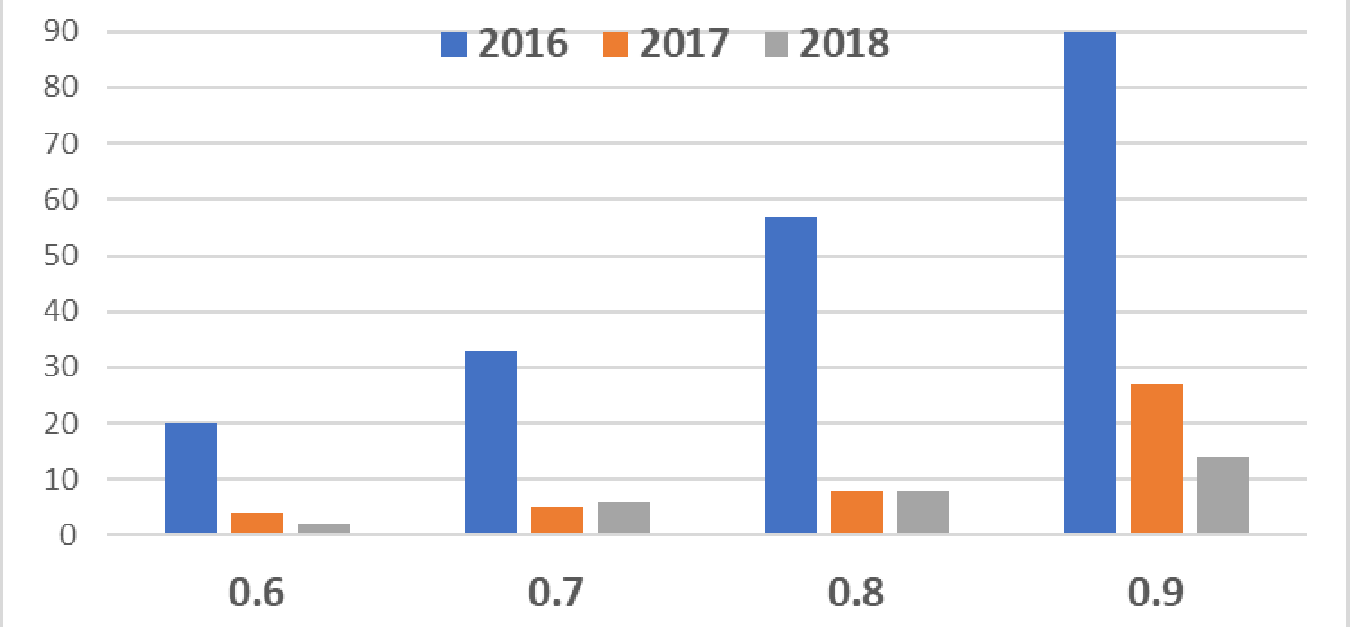
Notes

- As expected the isolated nodes **increase** with threshold.
- **Interesting**: isolated notes **decrease** with time in all thresholds.
- The network becomes **denser** (less isolated nodes, means more edges in the network), which is a confirmation that the **synchronization** among the cryptocurrencies' prices increases.
- Evidence of market **convergence**. It becomes a market with common features and characteristics.

Dominant Cryptocurrencies

Isolated Nodes – not interconnected part of the network

- Per year
- Per threshold



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Dominant Cryptocurrencies

Dominant and Interconnected Nodes

- Per year
- Per threshold

Table 3
TW-MDS metrics concerning the dominant and the interconnected nodes for various threshold instances. In parentheses is the percentage of the network that is interconnected after the Threshold step.

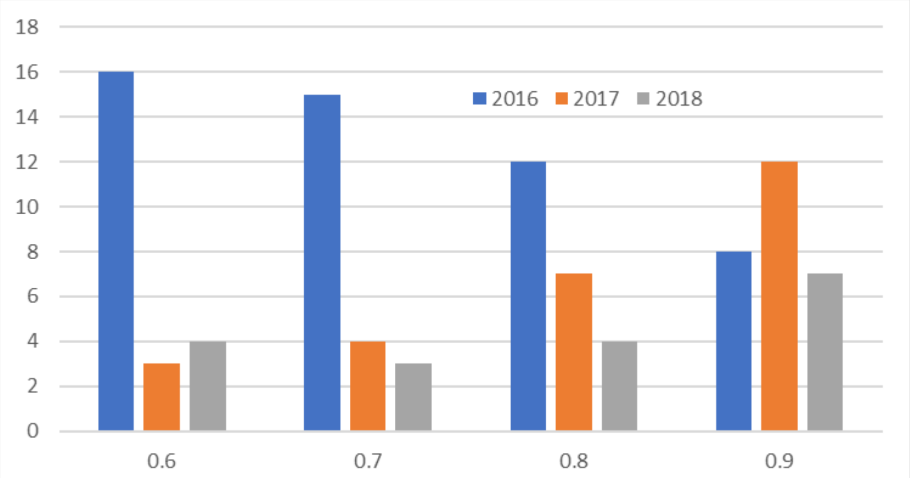
Threshold	2016		2017		2018	
	Dominant nodes	Interconnected nodes	Dominant nodes	Interconnected nodes	Dominant nodes	Interconnected nodes
0.6	16	92 (82.1%)	3	108 (96.4%)	4	110 (98.2%)
0.7	15	79 (70.5%)	4	107 (95.5%)	3	106 (94.6%)
0.8	12	55 (49.1%)	7	104 (92.9%)	4	104 (92.9%)
0.9	8	22 (19.6%)	12	85 (75.9%)	7	98 (87.5%)

Notes

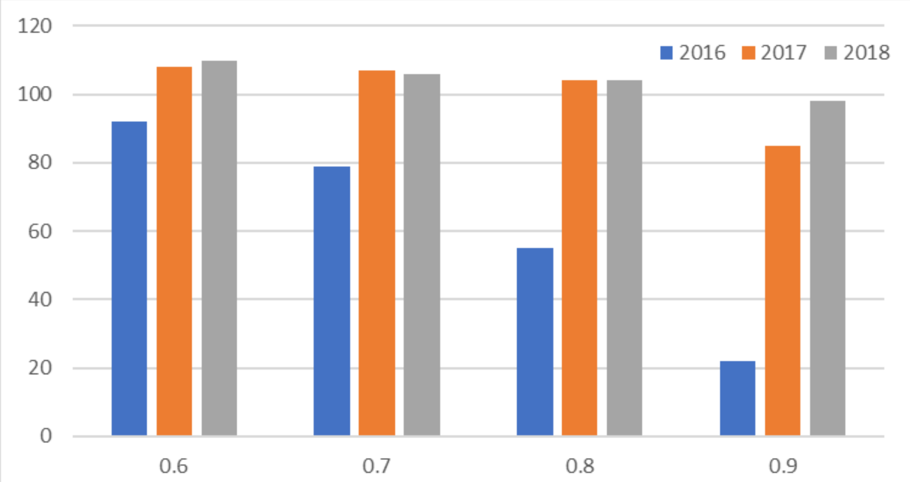
- **Less** dominant nodes from year to year for all thresholds.
- The networks behavior can be explained by **fewer cryptos**.
- The **percentage** of the interconnected part (explained by the MDS) becomes **larger**.
- We have seen **isolated** nodes becoming **less**.
- More **evidence** on the **convergence**.
- Less isolated and less dominant nodes means the network is concentrated and becomes denser with common behavior.

Dominant Cryptocurrencies

Dominant and Interconnected Nodes



Dominant Nodes



Interconnected Nodes

Notes

- **Less** dominant nodes from year to year for all thresholds.
- The networks behavior can be explained by **fewer cryptos**.
- The **percentage** of the interconnected part (explained by the MDS) becomes **larger**.
- We have seen **isolated** nodes becoming **less**.
- More **evidence** on the **convergence**.
- Less isolated and less dominant nodes means the network is concentrated and becomes denser with common behavior.

Dominant Cryptocurrencies

Network Metrics: AND, ACC, Density

Table 4
Network's topology properties for various threshold levels.

Panel A (Threshold Level 0.6)			
	2016	2017	2018
AND[a]	14.982	81.821	94.518
ACC	0.711	0.902	0.967
Density	0.135	0.737	0.852
Panel B (Threshold Level 0.7)			
	2016	2017	2018
AND	8.518	64.964	89.625
ACC	0.624	0.838	0.974
Density	0.077	0.585	0.807
Panel C (Threshold Level 0.8)			
	2016	2017	2018
AND	2.804	37.411	79.714
ACC	0.686	0.752	0.939
Density	0.025	0.337	0.718
Panel D (Threshold Level 0.9)			
	2016	2017	2018
AND	0.411	8.482	46.821
ACC	0.628	0.625	0.846
Density	0.004	0.076	0.422

[a]AND stands for Average Node Degree. ACC stands for Average Clustering Coefficient.

Dominant Cryptocurrencies

Network Metrics: AND, ACC, Density

Panel D (Threshold Level 0.9)

	2016	2017	2018
AND	0.411	8.482	46.821
ACC	0.628	0.625	0.846
Density	0.004	0.076	0.422

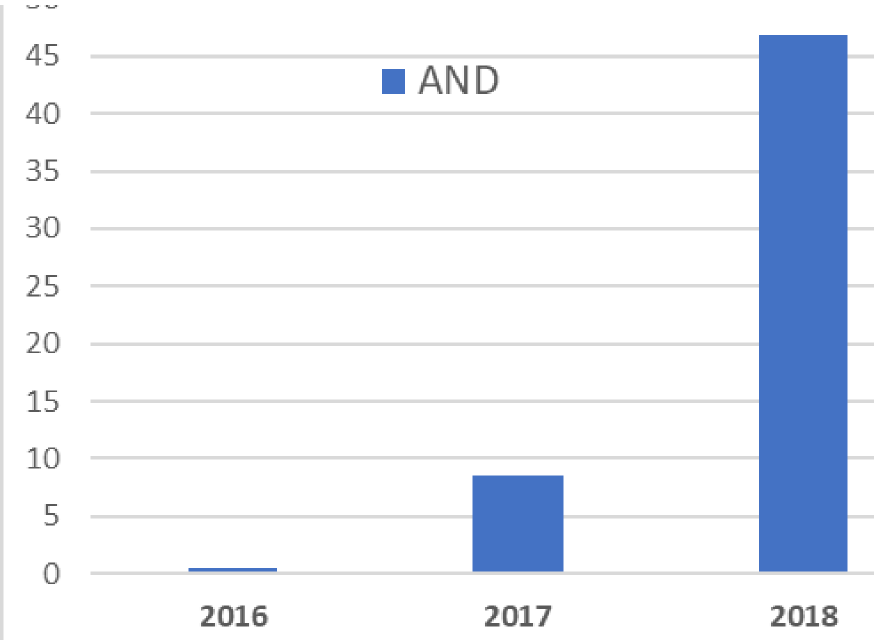
[a]AND stands for Average Node Degree. ACC stands for Average Clustering Coefficient.

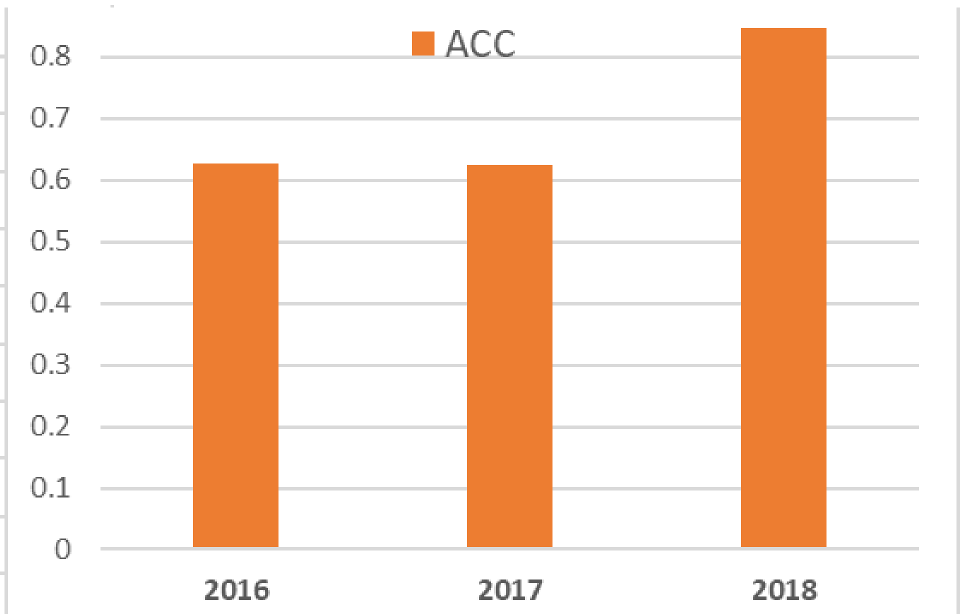
- AND (Average Node Degree) = the average edges per node.
- ACC (Average Clustering Coefficient) = average clustering per node.
- Density = total connections over all possible connections in the network

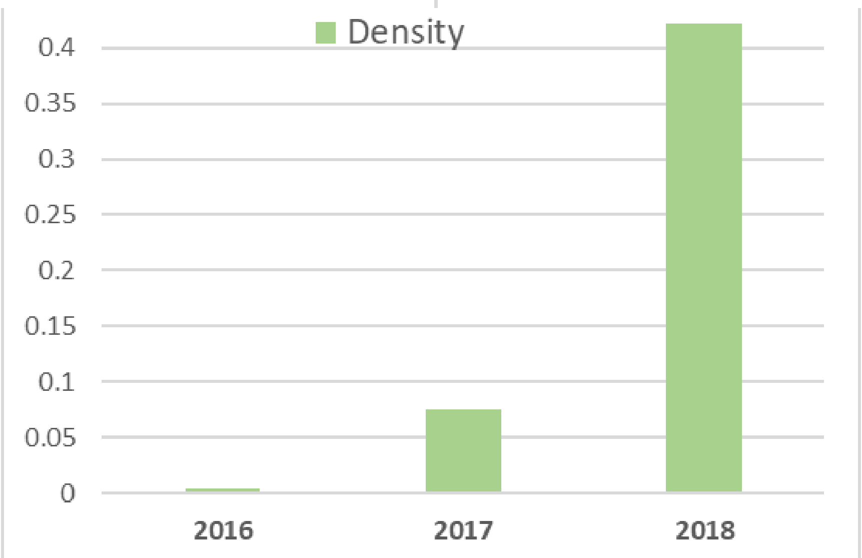
- All metrics point to **increased convergence** and **similarity**.

Dominant Cryptocurrencies

Network Metrics: AND, ACC, Density

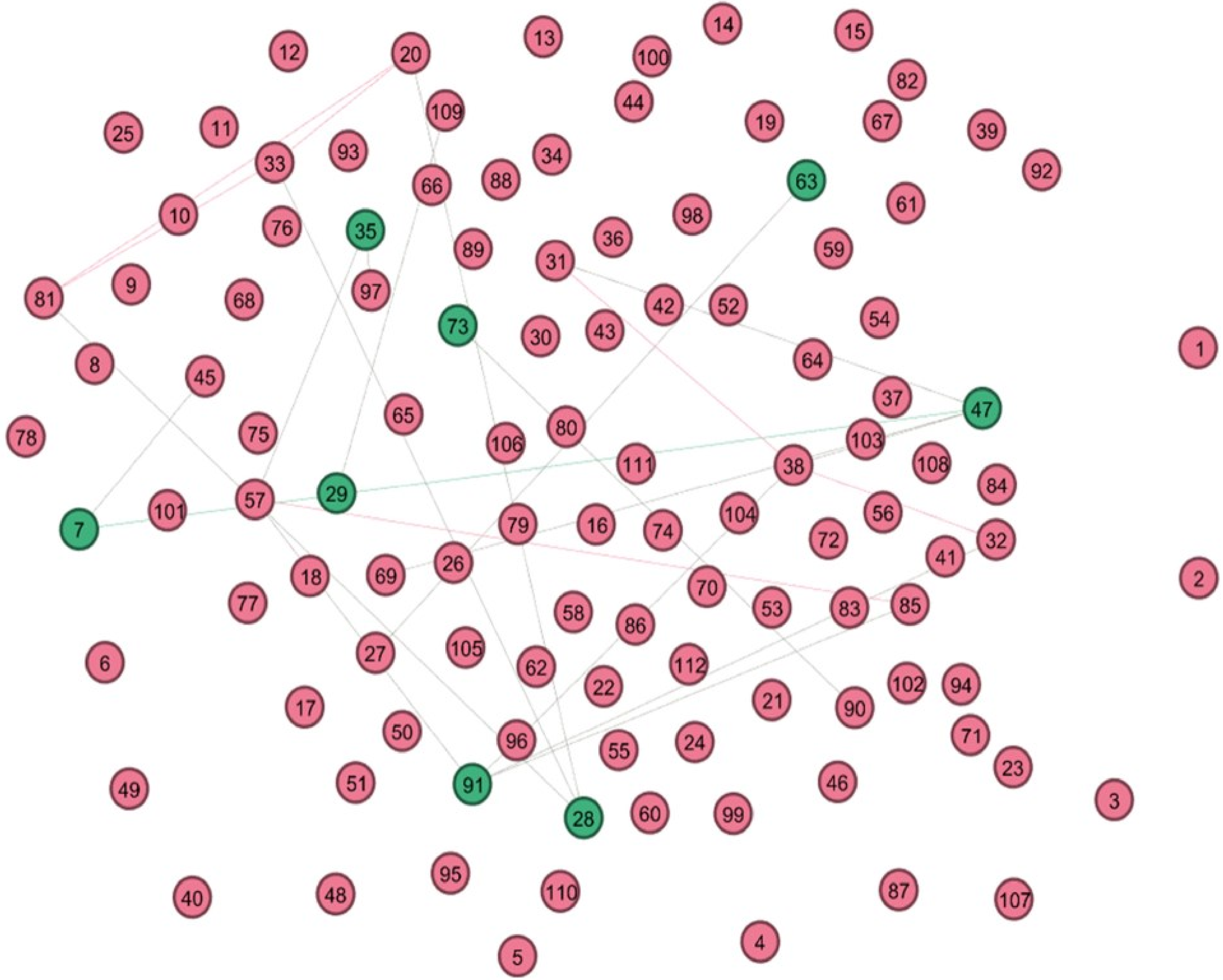






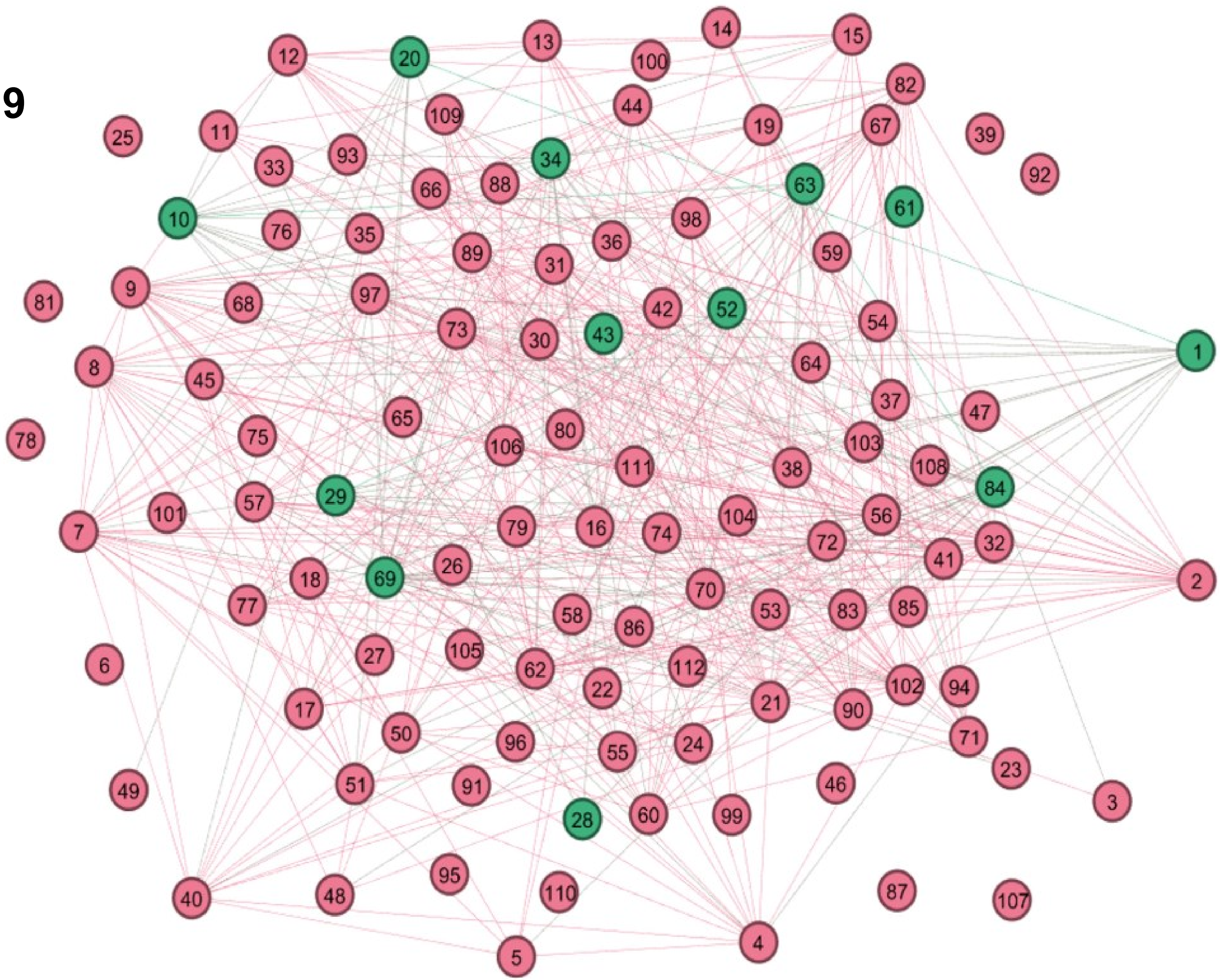
Dominant Cryptocurrencies

2016
Threshold 0.9



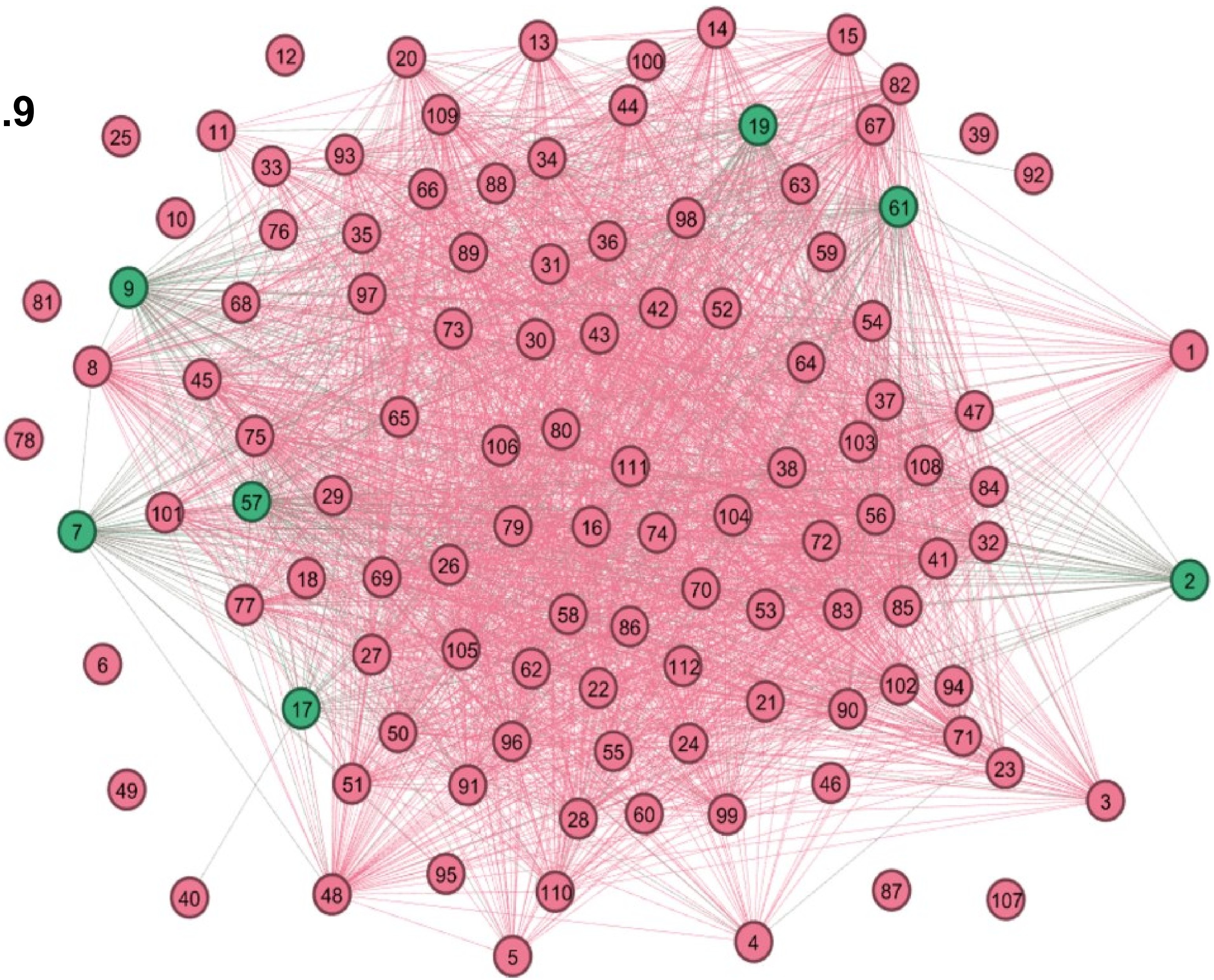
Dominant Cryptocurrencies

2017
Threshold 0.9



Dominant Cryptocurrencies

2018
Threshold 0.9



Dominant Cryptocurrencies

- **Identification of Dominant Nodes per year**
- **Threshold 0.9**

2016		2017		2018	
Dominant nodes	Neighborhood cardinality[a]	Dominant nodes	Neighborhood cardinality[a]	Dominant nodes	Neighborhood cardinality[a]
Monero	2	Bitcoin	15	Ethereum	41
Peercoin	3	Dogecoin	17	Monero	52
Blocknet	1	MonaCoin	8	NEM	67
Gulden	2	Peercoin	3	MaidSafeCoin	36
IO Coin	4	Blocknet	9	ReddCoin	62
Myriad	1	Ubiq	15	Crown	61
Curecoin	1	GameCredits	1	SolarCoin	60
Bitcoin Plus	4	FairCoin	6		
		SolarCoin	1		
		Myriad	16		
		Gambit	22		
		DopeCoin	16		

Dominant Cryptocurrencies

- **Identification of Isolated Nodes per year**
- **Threshold 0.9**

2016				2017	2018
Isolated nodes				Isolated nodes	Isolated nodes
Bitcoin	DigitalNote	Omni	AudioCoin	Tether	Tether
Ethereum	BitCNY	Circuits of Value	DigitalPrice	Unobtanium	Dogecoin
Ripple	WhiteCoin	GoldCoin	HyperStake	Clams	Bytecoin
Litecoin	BlackCoin	Anoncoin	Neutron	BitCNY	Groestlcoin
Stellar	BitBay	OKCash	BunnyCoin	Primecoin	Unobtanium
Tether	GameCredits	NewYorkCoin	Canada eCoin	Xaurum	BitCNY
Dash	Counterparty	BitSend	SpreadCoin	Pandacoin	Primecoin
NEM	Primecoin	Capricoin	Adzcoin	MintCoin	Global Curr. Res.
Dogecoin	PotCoin	Terracoin	Universal Currency	Dotcoin	Anoncoin
DigiByte	Global Currency Reserve	GCN Coin		Anoncoin	Capricoin
Bytecoin	Stealth	ArtByte		OKCash	Novacoin
BitShares	Feathercoin	ExclusiveCoin		NewYorkCoin	MaxCoin
Verge	FairCoin	DopeCoin		Capricoin	Zeitcoin
Siacoin	Xaurum	Pura		GCN Coin	BunnyCoin
Factom	VeriCoin	MaxCoin		Novacoin	
MaidSafeCoin	CloakCoin	Bullion		MaxCoin	
Groestlcoin	Diamond	Auroracoin		Bitcoin Plus	
ReddCoin	HempCoin	FedoraCoin		FedoraCoin	
Syscoin	Pandacoin	NeosCoin		Zeitcoin	
Nxt	Bean Cash	Zeitcoin		Orbitcoin	
Nexus	SolarCoin	Orbitcoin		LiteDoge	
Vertcoin	MonetaryUnit	CannabisCoin		AudioCoin	
Unobtanium	MintCoin	HunterCoin		DigitalPrice	
Clams	ECC	Bitmark		BunnyCoin	
Emercoin	GridCoin	LiteDoge		SpreadCoin	
Ubiq	Sphere	Bitzeny		Adzcoin	
FLO	Dotcoin	e-Gulden		Universal Curr.	

Dominant Cryptocurrencies

Conclusions

- Both simple graph metrics and the resulting TW-MDS topology provide evidence of a temporal trend towards **increased synchronization** of the cryptocurrencies market prices.
- More specifically:
    a. With each year passing the network becomes **denser** as more cryptocurrencies exhibit **similar behavior**
    b. Fewer cryptocurrencies display an **idiosyncratic** behavior as it is evidenced by the **decreasing** number of the **isolated** nodes and
    c. Dominant nodes, i.e. the nodes that can represent the collective behavior of their entire neighborhood are **fewer** implying that the network evolves over time by forming **less** but **highly populated neighborhoods** of cryptocurrencies.
    These behave in a highly similar manner as it is assured by the imposed threshold. All these results provide strong evidence of increased synchronization in the cryptocurrencies market.
- Evolution towards a more synchronized market is evident.

Dominant Cryptocurrencies

Conclusions

- Each currency is at a **different maturity state** as they were introduced in **different points in time**.
- With time, they **mature** and are seen in the eyes of the investors as more **homogeneous** assets, becoming increasingly better **substitutes** of each other.
- Thus, their time series properties, i.e. **returns** and **volatility**, are **expected** to **converge** with time and this is confirmed from this study:
- Their **correlation coefficients increase** and this is reflected in an **exponentially decreasing** number of **isolated** nodes and the creation of a **denser** network with **fewer** dominant nodes and **highly** populated individual **neighborhoods**.

Dominant Cryptocurrencies:

A complex networks approach

Periklis Gogas – Professor DUTH