A Study of Standards and Innovation
A Case of the Internet of Things (IoT) with focus on China

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Current Status of Research

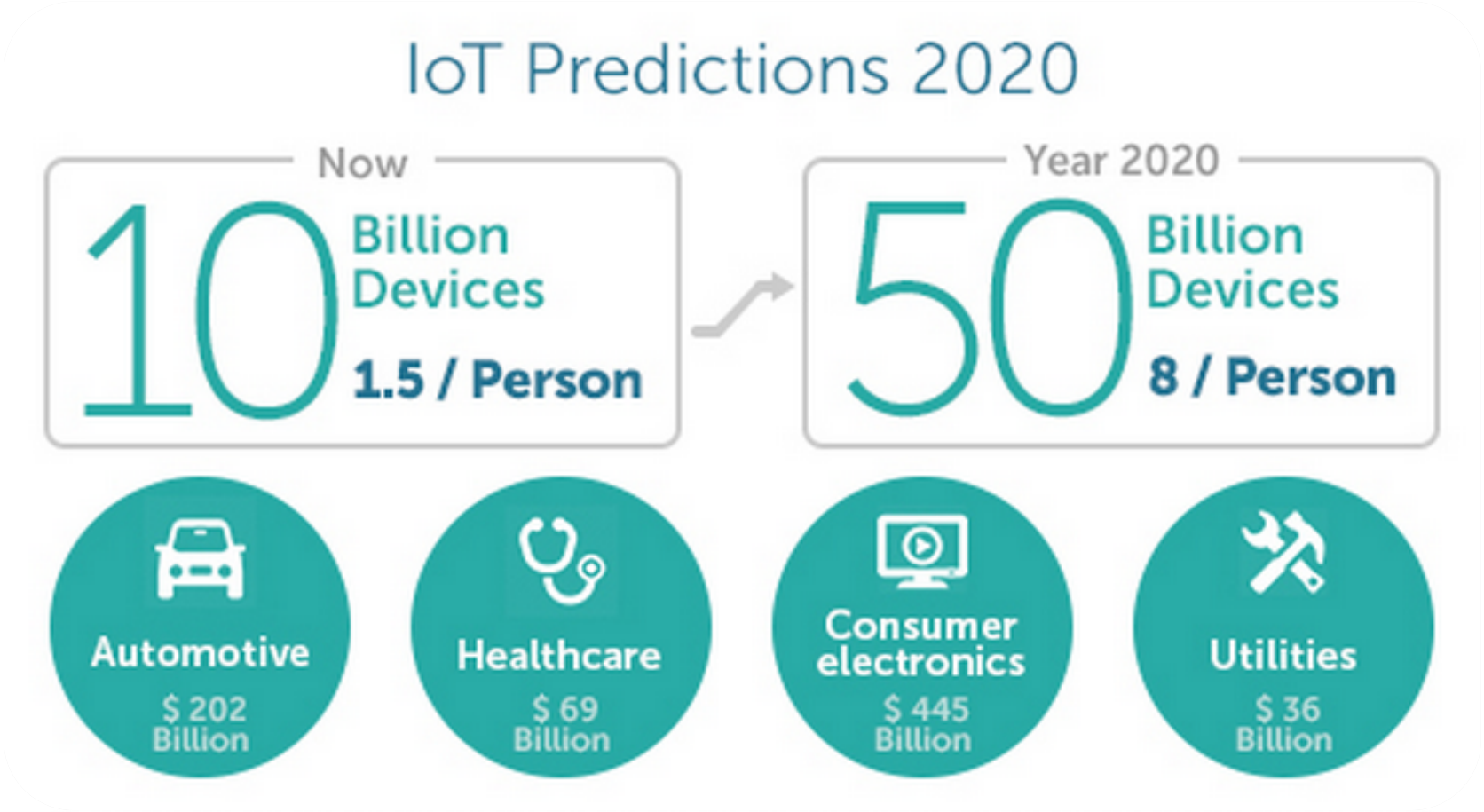
- First part of research has recently been published in *Research Policy*, a top-ranked journal in innovation studies, entitled ""Standards as a driving force that influences emerging technological trajectories in the converging world of the Internet and things: An investigation of the M2M/IoT patent network".

- Second part of research has been submitted to ICIS 2017 (International Conference on Information Systems), entitled "The dynamics of technological rationality and primacy of power: A case of Huawei and Ericsson's standardization of NB-IoT", targeting *Journal of Management Information Systems or Journal of International Business Studies*.

- Additionally, I have been conducting a theory-building study on standards and innovation, relying on Niklas Luhmann's works, targeting *MIS Quarterly*.

Research Background

- Emergence of the Internet of Things (IoT) as a New Technological Paradigm



Source: Cisco & Machina Research
from claricetechnologies.com

Problem statement 1

- *Effect of standards on emerging technological trajectories*
  - Prior studies focus on theoretical explanations between these two concepts (Metcalfe & Miles, 1994), requiring an empirical study.

- *Effect of standards on the relationship between technological importance and diversity*
  - Standards played a critical role in digital convergence (Yoffie, 1997). However, it has not yet been empirically shown how standards affect technological convergence.

- *Identification of influential IoT standards, strategic patents and strategic groups*
  - This will help us to understand the dynamics of strategic competition, revolving around the M2M/IoT trajectory, in the catch-up context.

Problem statement 2

- *Dynamics of technological rationality and primacy of power*
  - Previous literature has not taken strategic alliances and temporal elements, such as deadline, into consideration when it explains the relationship between technological rationality and primacy of power in standardization.

- *Huawei's IoT strategy*
  - Considering the growing importance of Chinese firms' strategies in the global ICT market, the analysis of Huawei's IoT strategy offers practical implications.

Research Questions

- To find the effects of standards on the M2M/IoT trajectory
  - How standards affect the shaping of the M2M/IoT trajectory?
  - How standards affect technological convergence in terms of technological importance and technological diversity?
  - What are the influential standards, strategic patents and strategic groups in the M2M/IoT trajectory?

- To reveal the dynamics of technological rationality and primacy of power in the NB-IoT standardization
  - How have technological rationality and primacy of power affected the NB-IoT standardization?
  - What are the strategic differences between Huawei and Ericsson?

Overview of the Internet of Things (IoT)

- The origin of the *Internet of Things* (IoT) can be traced back to the concept *ubiquitous computing*, proposed in Mark Weiser's Scientific American article, "The Computer for the 21st Century" in 1991.
  - His vision of future technological ubiquity contains increasing "availability" of processing power would be accompanied by its decreasing "visibility"
  - To this end, the following technologies need to be developed: 1) cheap, low-power computers, 2) a network that ties them all together, 3) software systems implementing ubiquitous applications.

- The term *Internet of Things* (IoT) started life when Kevin Ashton made his presentation at Procter & Gamble (P&G) in 1999, where he linked the idea of RFID in P&G's supply chain with the Internet.
  - The core idea of connecting things with the Internet and enabling them to work without human intervention remains the same.

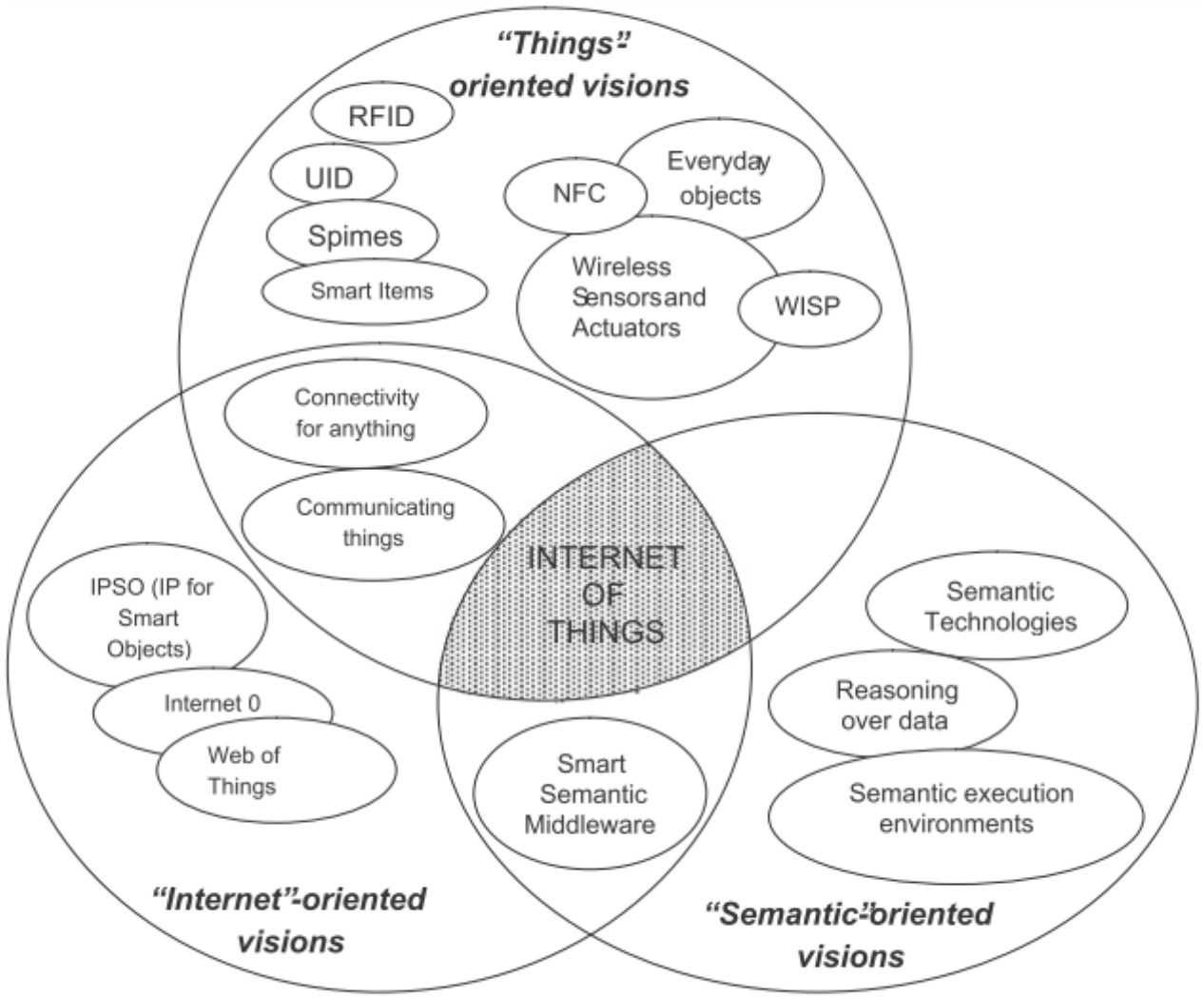
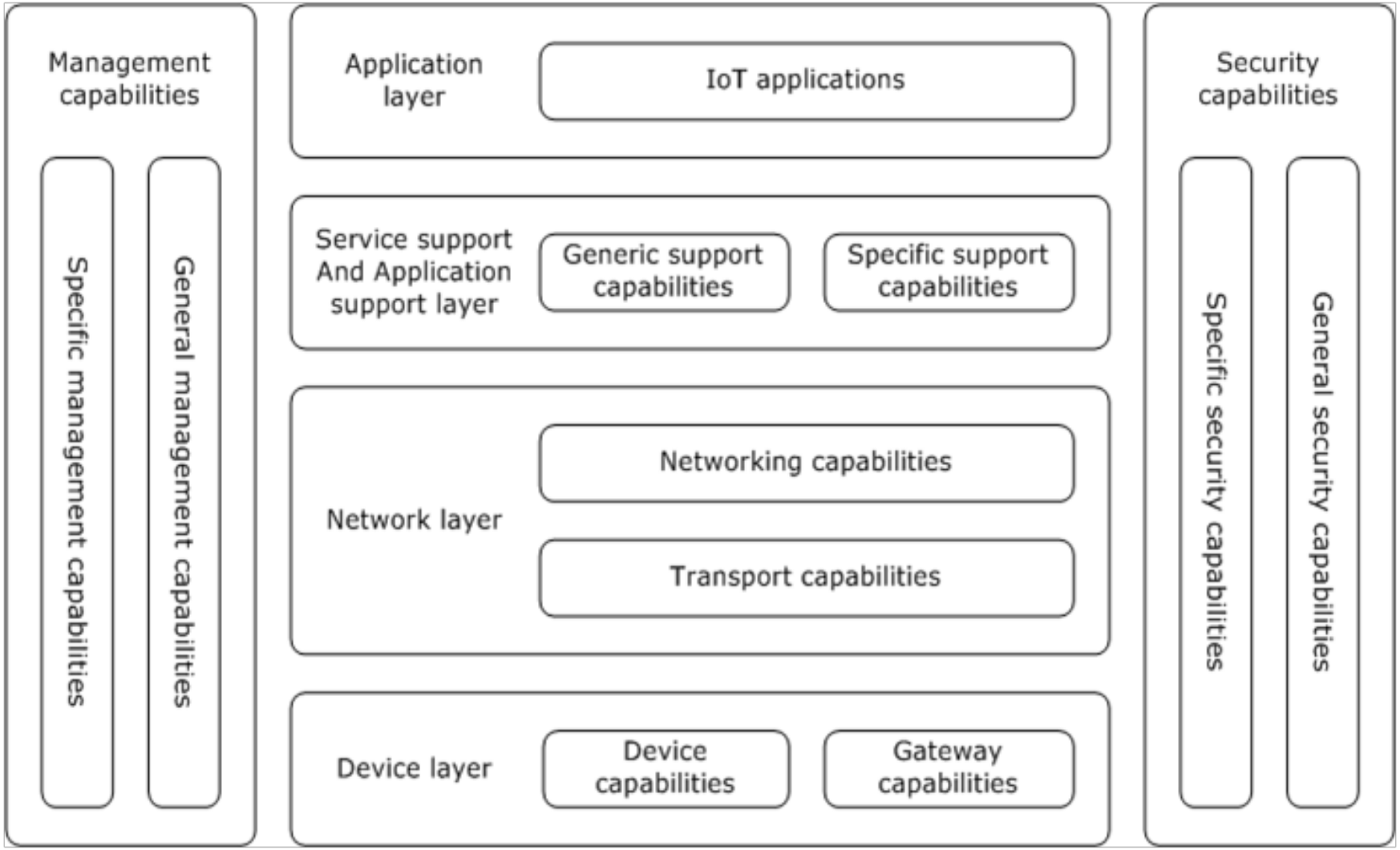


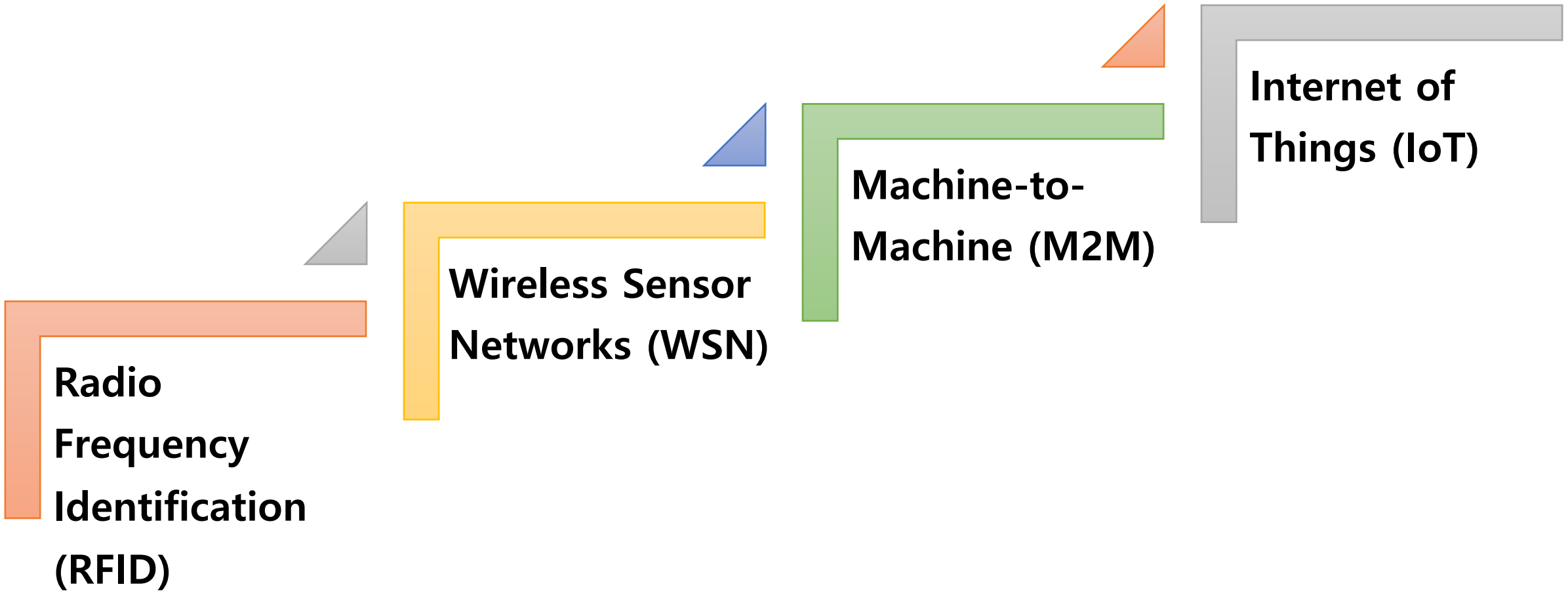
Fig. 1. "Internet of Things" paradigm as a result of the convergence of different visions.

IoT reference model



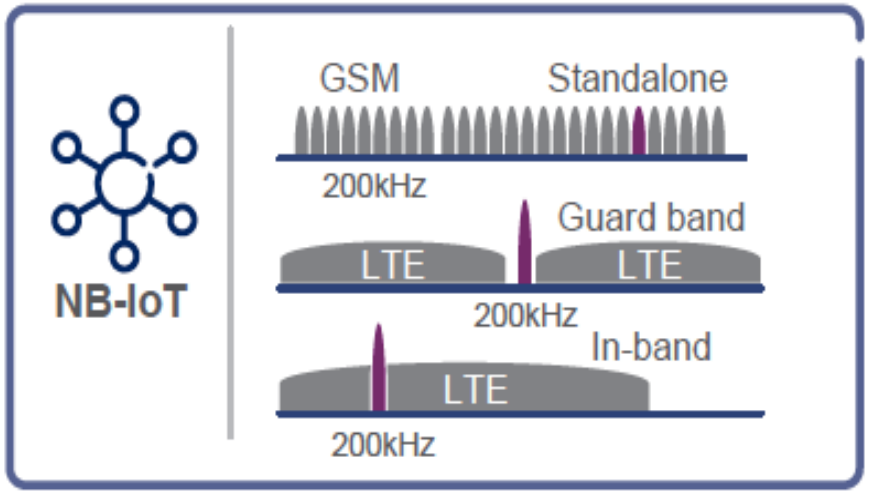
Source: ITU-T Y.2060

Technological Evolution of M2M/IoT



Low Power Wide Area Network (LPWAN)

Technology	Frequency band	Range	Data rate
LTE-M (Cat M1)	Between 450 MHz and 3.5 GHz	2.5-5 km	1 Mbps
NB-IoT	Between 450 MHz and 3.5 GHz	22 km	170-250 kbps
EC-GSM	850-900 MHz, 1.8-1.9 GHz	15 km	10 kbps
SigFox	868, 902 MHz	30-50 km	100 bps
LoRa	433, 868, 915 MHz	15-20 km	0.3-50 kbps



Empirical Analysis:
Investigation of the M2M/IoT Trajectory

Literature Review 1

- *M2M/IoT as a large technological system*

  - **IoT as a socio-technical system** in which the social and technical aspects of IoT are intertwined in a complex manner (Shin, 2014)

  - It is of significance to investigate the **historical development of IoT technologies within the social context** in which they are embedded (Bijker, 1995)

  - Issues regarding **compatibility between components in the system** and balance in their performance capabilities have been **crucial in the standards-setting process of emergent network technologies**, driven by various social actors (David & Bunn, 1988).

  - The sequential patterns of problem-solving activities arising from interdependencies among components in a large technological system (i.e. a change in one part becomes a problem in other parts) and the **significance of compatibility naturally lead to the necessity of understanding the path-dependent development (like trajectories) of technologies and the role of standards**

Literature Review 2

- *Technological trajectory and standard*

  - Due to the cumulative, irreversible nature of technological change, **technology advances along a technological trajectory**—"the pattern of 'normal' problem solving activity (i.e. of 'progress') on the ground of a technological paradigm" (Dosi, 1982, p. 152)

  - Recently, some researchers (e.g. Martinelli, 2012; Verspagen, 2007) attempted to **identity a technological trajectory via a top path in the patent citation network**, considering a patent is a useful proxy for engineering knowledge

  - By consolidating the meaning of a technical artifact into a common understanding (i.e. "closure" in Bijker's (1995) term), **standards shape a technological trajectory by stabilizing the variations of technological change and channeling them into a certain direction**

Literature Review 3

- *Standards and patents*
  - The age distribution of standards-essential patent citations (Rysman and Simcoe, 2008)
  - Standards also offer a function of variety-reduction that assists industry players in mitigating risks and achieving focus (Blind, 2004)
  - The similar structures of convergence in the spheres of patents and standards indicate a correlation between technological development and standardization (Gauch & Blind, 2015).

- **H1**: a reference to standards is positively associated with the importance of patents
- **H2**: a reference to standards is negatively associated with the generality of patents
- **H3:** a reference to standards moderates the relationship between the importance of patents and the generality of patents

Methodology 1

- *Patent citation network and main path analysis*
  - Social network analysis (Package: Gephi)
  - Community detection: modularity (Blondel et al., 2008)
  - Connectivity analysis (Hummon & Dereian, 1989) (Package: Pajek)

Main Path Analysis

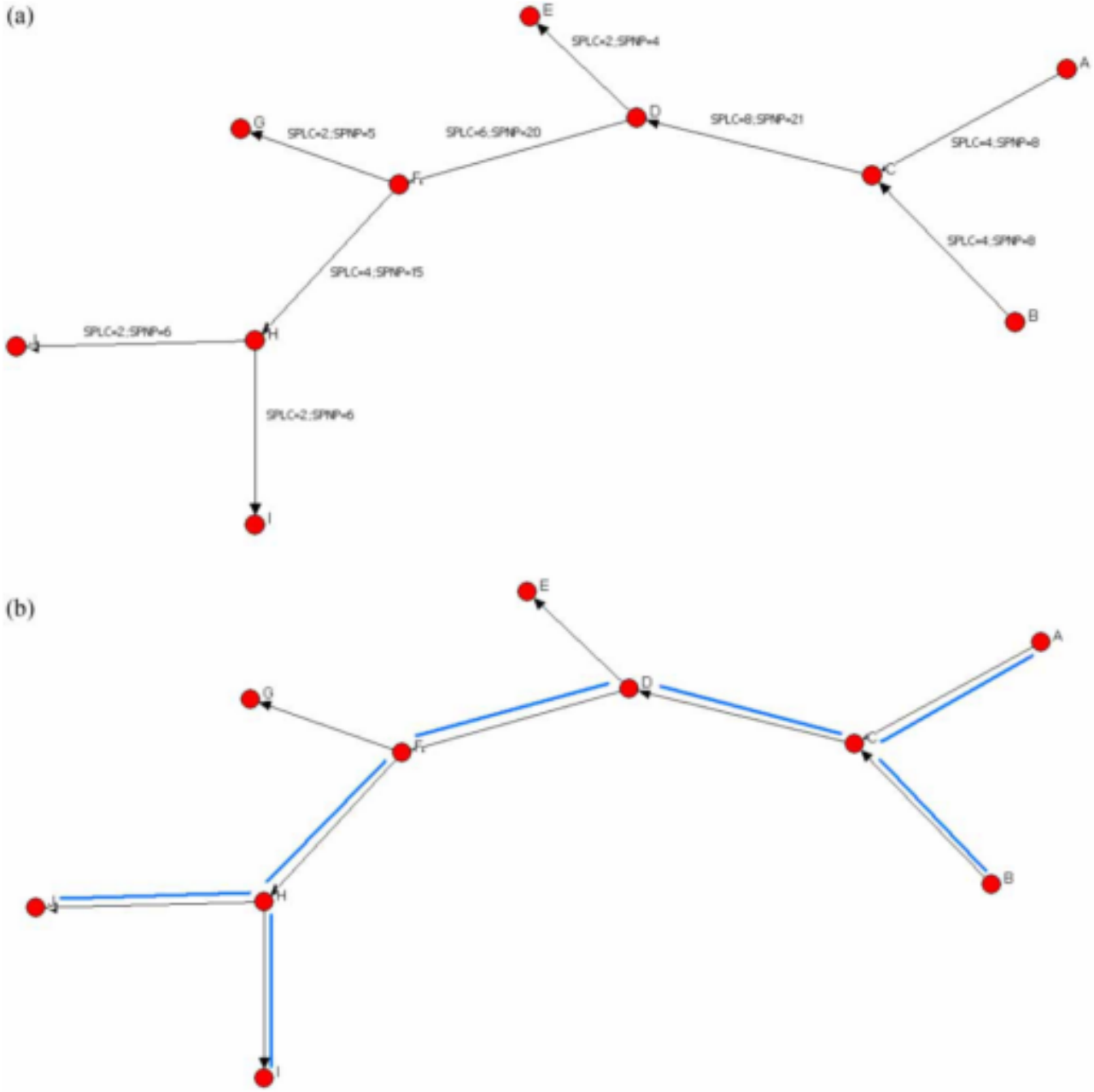


Figure 1. (A) Calculation of SPLC and SPNP. (B) The network of main paths.

Figure Source: Fontana, Nuvolari, & Verspagen (2009)

Methodology 2

- *Patent similarity and clustering analysis*

  - Latent semantic analysis (LSA), based on singular value decomposition (SVD), has often been used to examine patent text similarity (Han & Sohn, 2015) (Package: R)

  - Ward's hierarchical agglomerative clustering method was applied to identify patent clusters based on patent text similarity (Ward, 1963)

Methodology 3

- *Statistical analysis*

  - The Tobit model was mainly used to test the aforementioned hypotheses (H1: the number of adjusted forward citations as a dependent variable (DV) (Kang et al., 2014); H2: the generality of a patent as DV (Cassiman et al., 2008))

  - Powell's (1984) method for censored least absolute deviations (CLAD) is often used to estimate the effect of IVs on the conditional median of DV in the case of violating the assumptions of homoscedasticity and normal distribution of residuals, since this non-parametric regression method is robust to such violation (Sampat & Ziedonis, 2004)

Methodology 4

- *Statistical analysis*

  - For H3, the importance of patents is modified to measure the binding force of a technology, a source of attraction for technological interaction

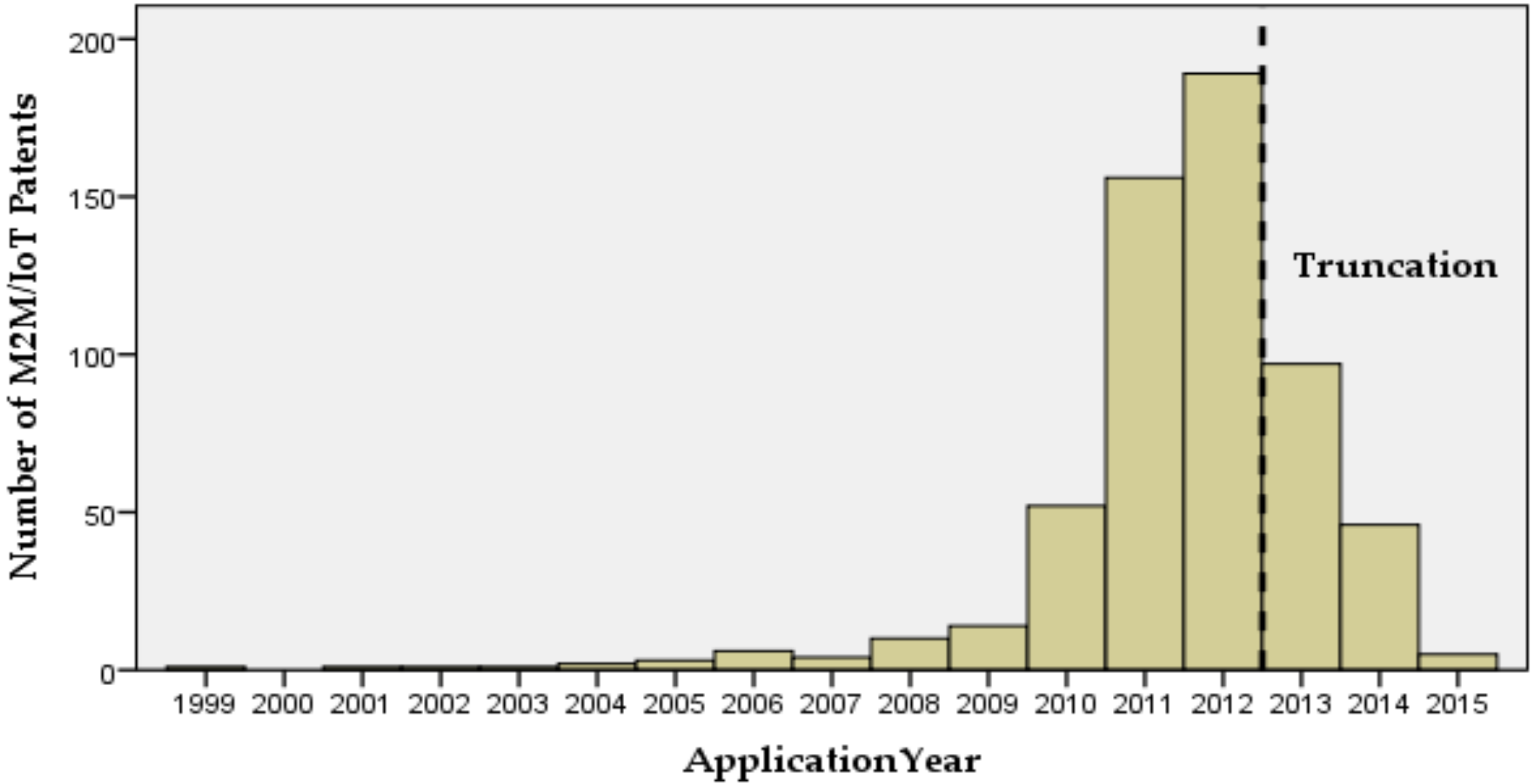
  - Following the gravity model, the importance of a patent (the count of adjusted forward citations) was weighted with the square of the patent's closeness centrality (Y. Cho & Kim, 2014)

  - A strong correlation between binding force (source of attraction) and generality (technological diversification) results from technological convergence

  - Subgroup analysis was performed to probe into the moderating role of standards (Sharma, Durand, & Gur-Arie, 1981) in the relationship between the binding force and generality

Data collection

- US patent citation data was extracted from **WIPS ON**, one of the largest online subscription-based patent databases in South Korea
- The researcher **double-checked** the accuracy of patent data by comparing it with data from the USPTO database and Google Patents
- The **CPC code**, a patent classification system, **H04W/005** (Mobile application services or facilities specially adapted for wireless communication networks for Machine-to-Machine communication [M2M, MTC]), was used to select the patent search scope
- As of December 2015, **588 M2M/IoT granted patents** were searched and their backward/forward citation data was extracted (**7792 patent citation data**)


Number of M2M/IoT Patents
200
150
100
50
0
Truncation
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
ApplicationYear

Findings: 1) M2M/IoT Communities and Strategic Patents

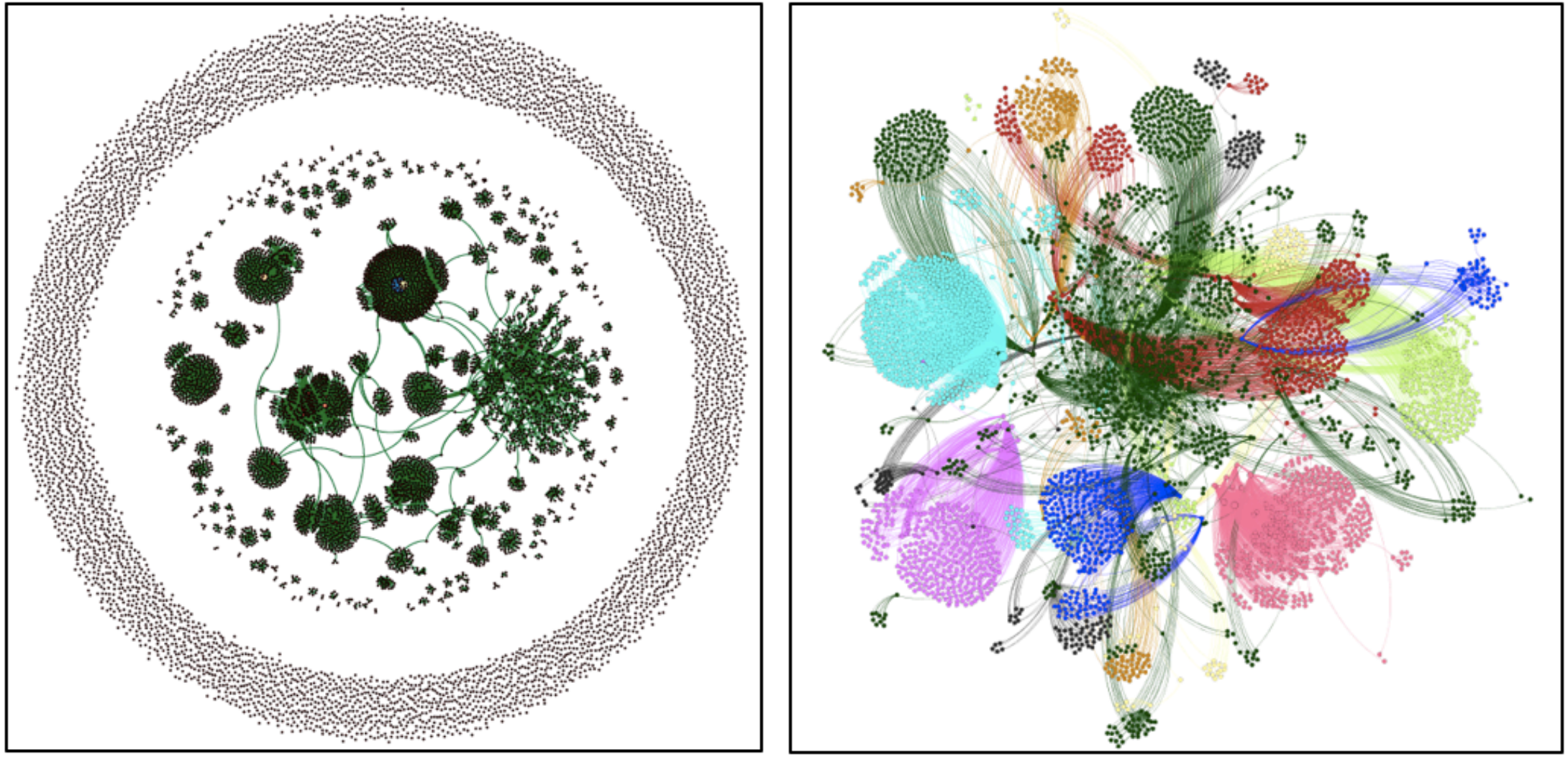
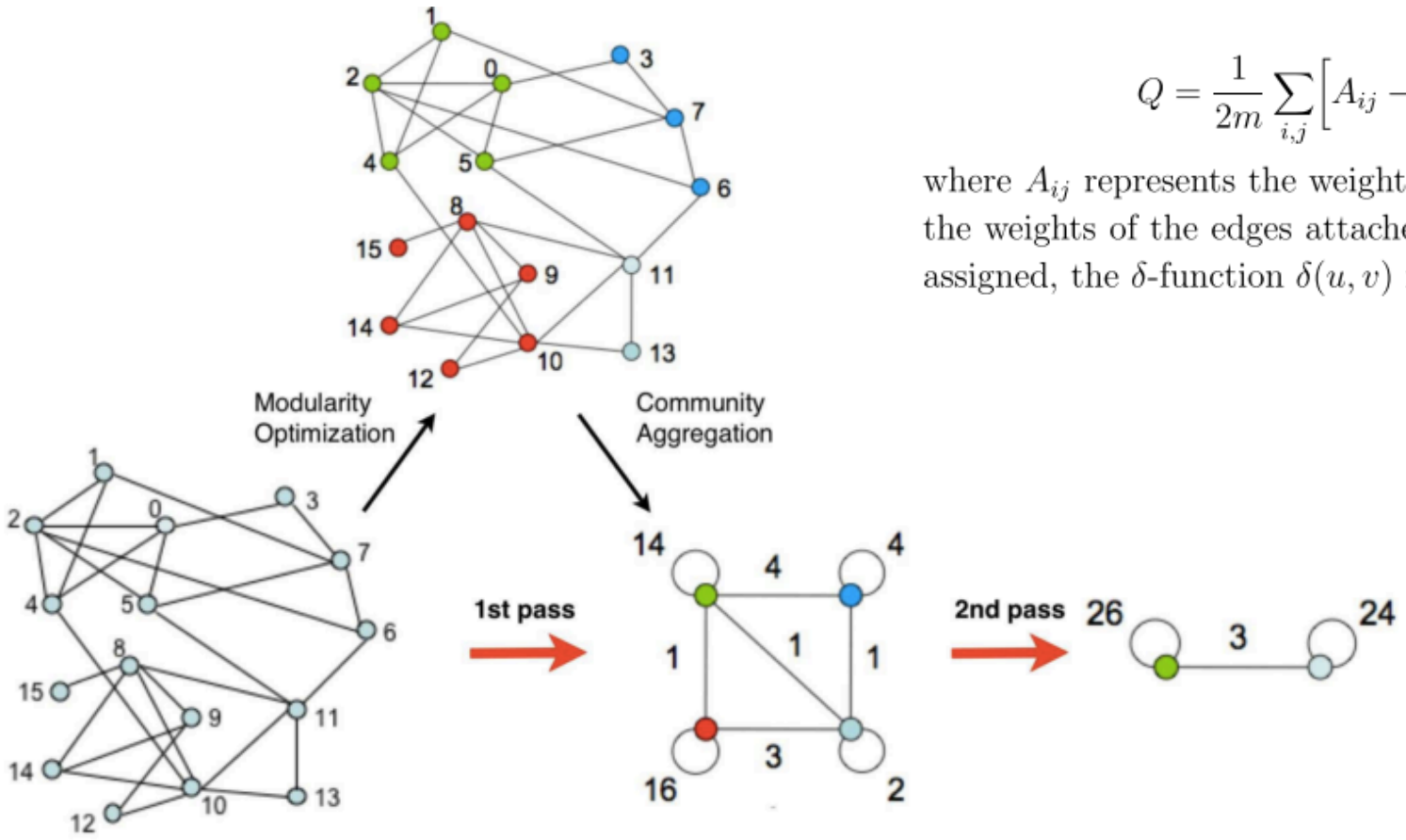


Figure 2. The overall citation network structure of M2M/IoT patents (Left) and top 10 communities (Right)

Modularity optimization (Blondel et al., 2008)

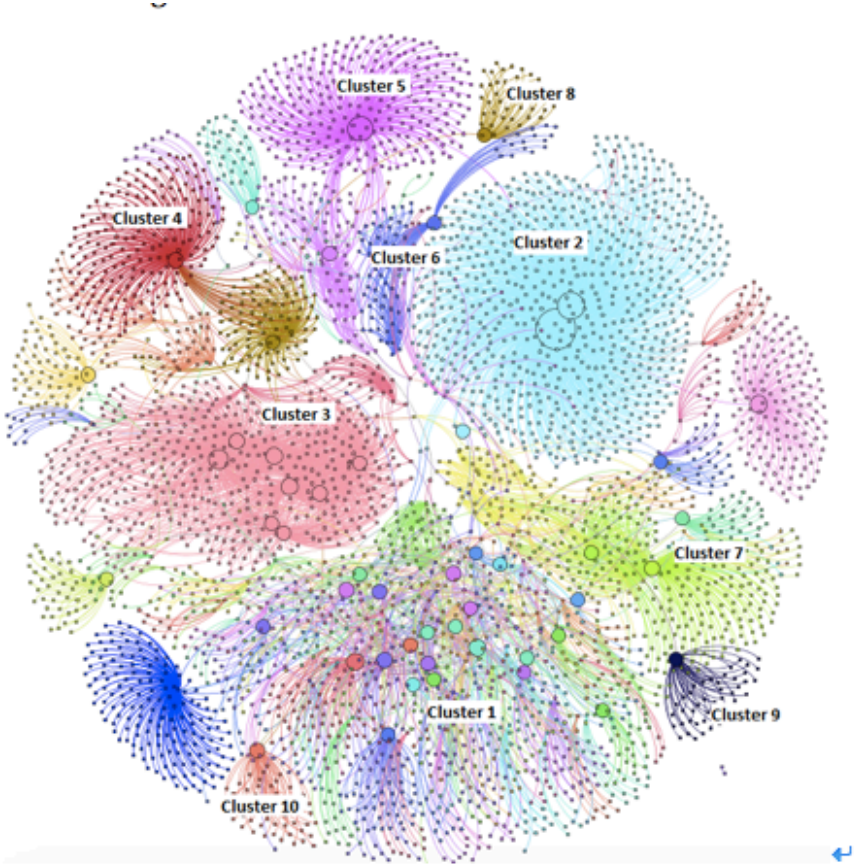


$$Q = \frac{1}{2m} \sum_{i,j} \left[A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i, c_j), \tag{1}$$

where A_{ij} represents the weight of the edge between i and j, $k_i = \sum_j A_{ij}$ is the sum of the weights of the edges attached to vertex i, c_i is the community to which vertex i is assigned, the δ-function $\delta(u, v)$ is 1 if $u = v$ and 0 otherwise and $m = \frac{1}{2} \sum_{ij} A_{ij}$.

Figure 1. Visualization of the steps of our algorithm. Each pass is made of two phases: one where modularity is optimized by allowing only local changes of communities; one where the found communities are aggregated in order to build a new network of communities. The passes are repeated iteratively until no increase of modularity is possible.

Verification of the results by the Chinese Whispers algorithm (Biemann, 2006)



Clusters 1–10 similarly matches communities 1–10, detected by Blondel et al.'s modularity optimization method, as shown in Figure 2. The size of nodes is measured based on betweenness centrality.

Table 2. The assignees of the top 10 patents in the top 10 communities in the M2M/IoT patent citation network

1 (26.36%)	2 (14.05%)	3 (8.46%)	4 (7.3%)	5 (6.21%)	6 (5.95%)	7 (5.2%)	8 (3.19%)	9 (2.95%)	10 (1.73%)
InterDigital (8718688)	Seven Networks (9060032)	Google (9223323)	Mueller Intl (8855569)	Robin Dua (8244179)	iRobot (8265793)	Benjamin Slotznick (7058356)	Nielsen (8930003)	CNH America (8280595)	IBM (7769848)
Symstream (8135362)	Seven Networks (9173128)	Google (9026254)	Magee Scientific (6317639)	Robin Dua (8583044)	DexCom (9028410)	Benjamin Slotznick (7496328)	Qualcomm (8606293)	SynapSense (7995467)	Infineon (8787266)
Apple (8737989)	LG (8811961)	Google (9092040)	Rain Bird (8649907)	Robin Dua (8463184)	iRobot (8892260)	Qualcomm (8831568)	Digimarc (8417793)	Blueforce (8467779)	N/A (8041772)
Ericsson (8407769)	Intel (8619654)	Google (9104211)	Rain Bird (8849461)	Robin Dua (9020429)	Welch (8458149)	Benjamin Slotznick (8131208)	N/A (8094949)	N/A (7917167)	N/A (8498224)
Via Telecom (8737265)	AT&T (9043503)	N/A (8489243)	N/A (6954701)	Robin Dua (8548381)	iRobot (8577501)	N/A (8472935)	ETRI (8116243)	IBM (7822852)	Verizon (8345546)
Samsung (9084074)	HTC (8438278)	Nest Labs (8752771)	N/A (6560543)	Robin Dua (Robin Dua)	DexCom (8844007)	Benjamin Slotznick (7856204)	Digimarc (9084098)	IBM (8898284)	Sprint (8848558)
Qualcomm (9210527)	Intel (8818376)	Nest Labs (8757507)	Sun Micro (7130773)	Robin Dua (8971803)	DexCom (9002390)	Qualcomm (8868038)	Digimarc (8671165)	SkyBitz (8971227)	Sprint (9160629)
Huawei (9107226)	Intel (9130688)	Nest Labs (8478447)	N/A (7424399)	Robin Dua (9160419)	N/A (7639715)	Amazon (8620208)	Nat'l Taiwan Univ (7839764)	Blueforce (8682309)	Sprint (9154976)
Cellco (7774008)	Alcatel Lucent (9208123)	Samsung (8392597)	Harris (8314717)	Robin Dua (9160420)	N/A (7327732)	Amazon (8718539)	Digimarc (8943172)	Blueforce (9066211)	Cubic (8824444)
Alcatel Lucent (9071925)	Huawei (9173244)	Ericsson (9049104)	N/A (7890568)	Robin Dua (9014631)	N/A (6456875)	Amazon (8666308)	Tangoe (9191523)	N/A (8233463)	Cubic (8824445)

Table 3. Strategic patents of M2M/IoT

Assignee (Number)	Application Year	Title	Connected Communities (In/Out)
Via Telecom (8737265)	2011	Methods and apparatuses for machine type communication	1 <- 2 (In)
LG (8811961)	2011	Method and apparatus for MTC in a wireless communication system	2 -> 1 (Out)
Seven Networks (8438633)	2006	Flexible real-time inbox access	1 -> 2 (Out), 1 <- 2 (In)
Seven Networks (9173128)	2013	Radio-awareness of mobile device for sending server-side control signals using a wireless network optimized transport protocol	2 <- 1 (In)
Seven Networks (9060032)	2012	Selective data compression by a distributed traffic management system to reduce mobile data traffic and signaling traffic	2 -> 1 (Out)
Vodafone (8838806)	2011	Connection management for M2M device in a mobile communication network	1 -> 7 (Out)
Qualcomm (8868038)	2012	Methods of and systems for remotely configuring a wireless device	7 <- 1 (In)
Qualcomm (8831568)	2012	Automatic configuration of a wireless device	7 <- 1 (In)
Magee Scientific (6317639)	1999	Automatic wireless data reporting system and method	4 -> 8 (Out)
Digimarc (8094949)	2000	Music methods and systems	8 <- 4 (In)
Benjamin Slotznick (7058356)	2001	Telephone device with enhanced audio-visual features for interacting with nearby displays and display screens	7 -> 9 (Out)
Iwao Fujisaki (7917167)	2008	Communication device	7 <- 9 (In)

2) M2M/IoT trajectory shaped by formal standards (3GPP in particular)

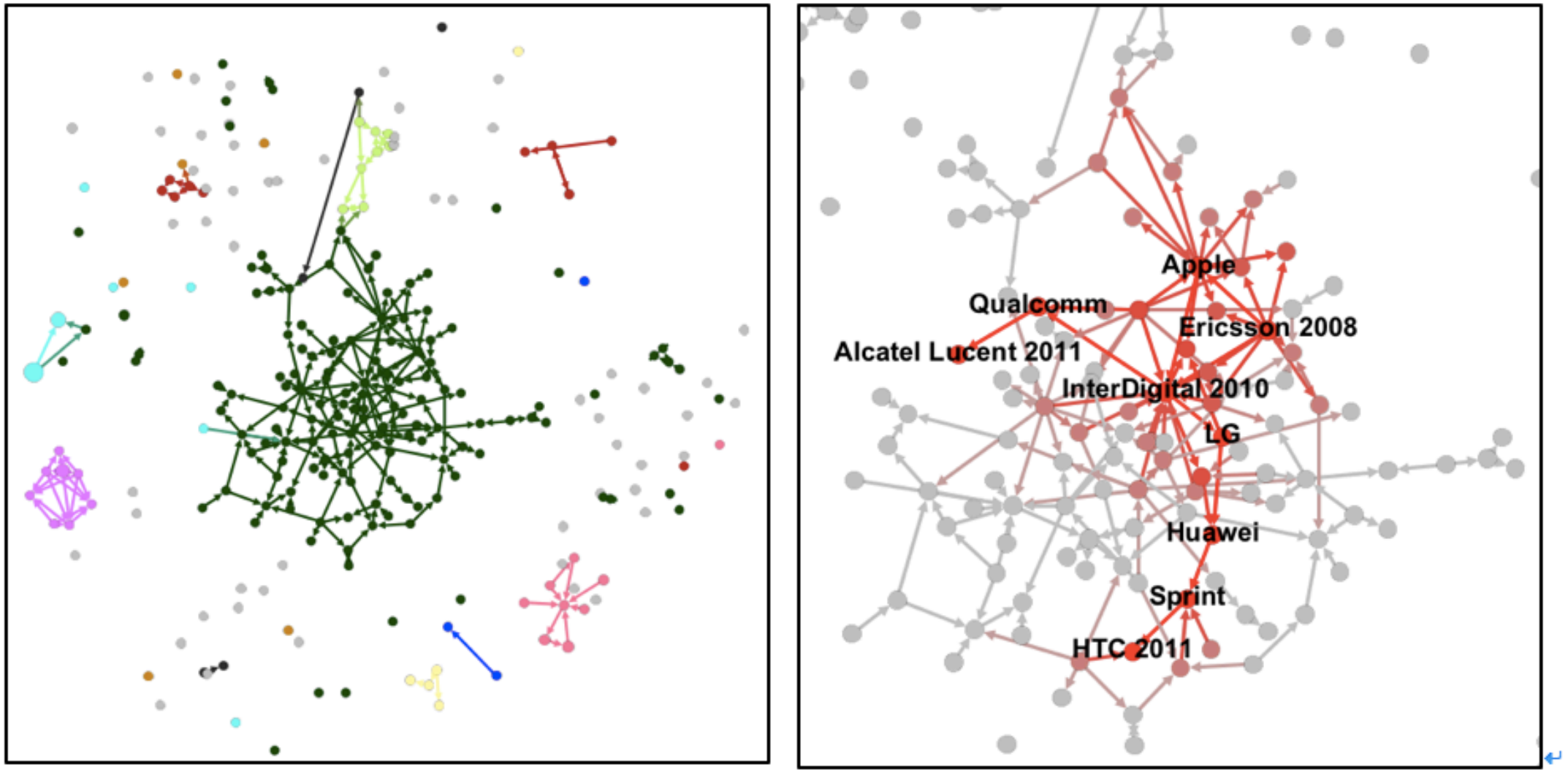
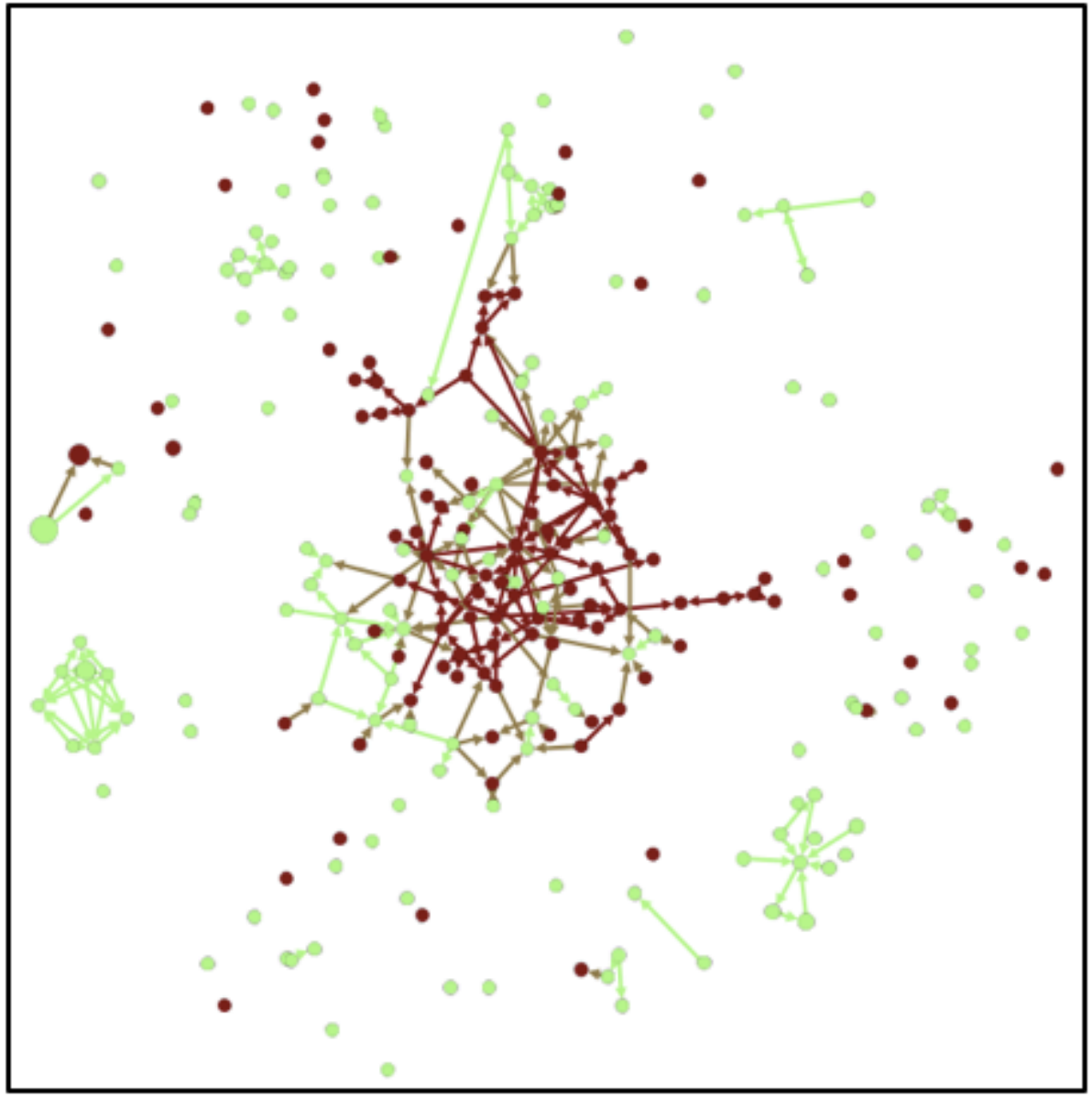


Figure 3. Patents with high betweenness centrality (top 5%) (Left) and M2M/IoT trajectory (Right)

Table 4. Patents that center on the M2M/IoT trajectory

Assignee (Number)	Application Year	Title	Standards
Ericsson (8407769)	2008	Methods and apparatuses for machine type communication	3GPP TR 33.812, 3GPP TS 43.020
Apple (8737989)	2008	Methods and apparatus for machine-to-machine based communication service classes	3GPP TS 23.008, ITU-T Q.763
InterDigital (8718688)	2010	Method and apparatus for solving limited addressing space in machine-to-machine (M2M) environments	3GPP TR 22.868, 3GPP TS 23.003, 3GPP TS 23.060
Qualcomm (9210527)	2011	Method and apparatus for providing uniform machine-to-machine addressing	
Alcatel Lucent (9071925)	2011	System and method for communicating data between an application server and an M2M device	3GPP TS 22.368
HTC (9167470)	2011	Handling signaling congestion and related communication device	3GPP TS 22.368. 3GPP TS 23.107, 3GPP TR 23.888, IEEE Std 802.11
LG (9137624)	2012	Method and device for performing ranging in a wireless communication system	
Huawei (9107226)	2012	Method and system for handling congestion in a communications system	IEEE P802.16b/D2, IEEE P802.16p/D3, IEEE 802.16m-08/004r2
Sprint (8638724)	2012	Machine-to-machine traffic indicator	



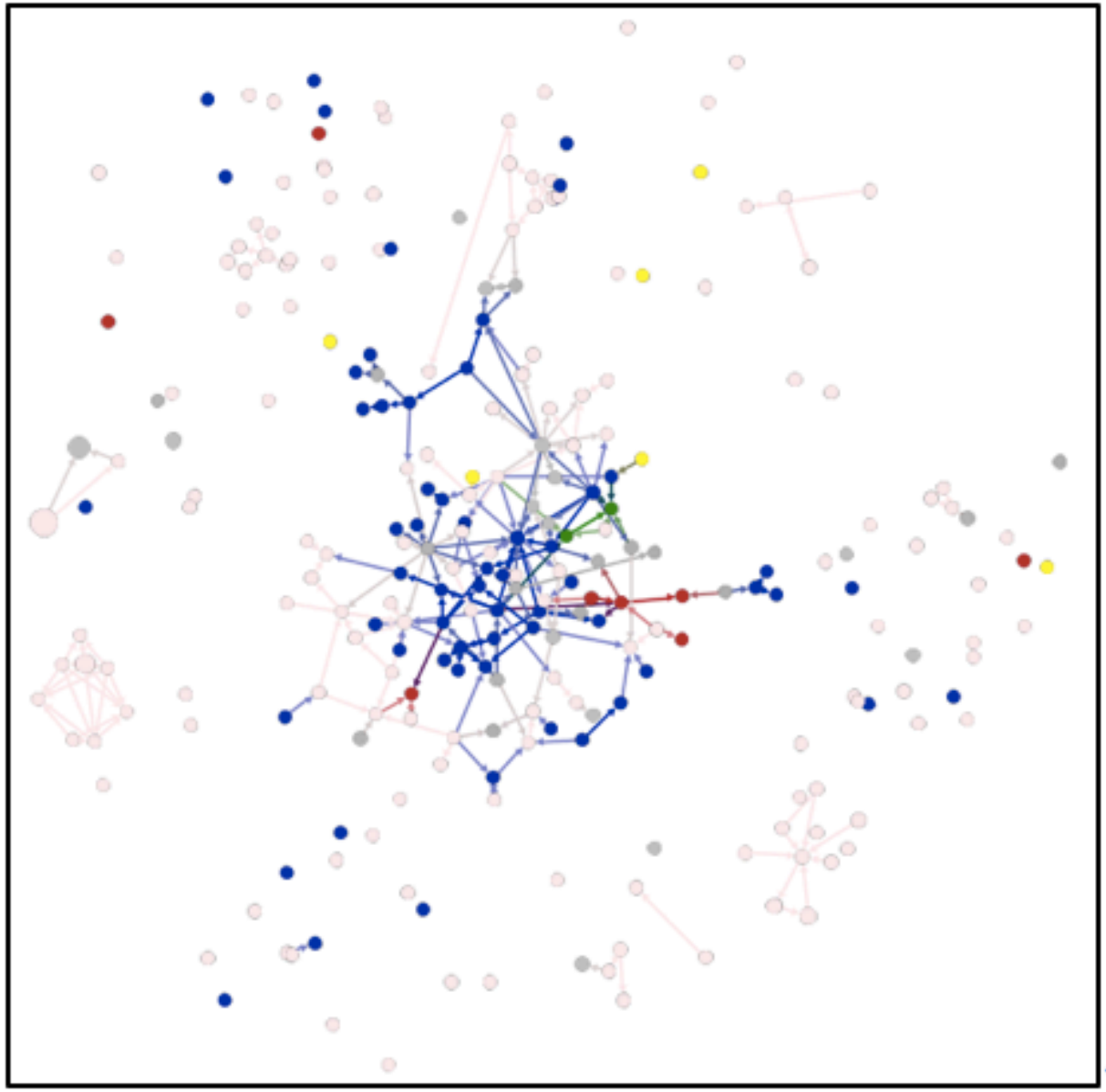


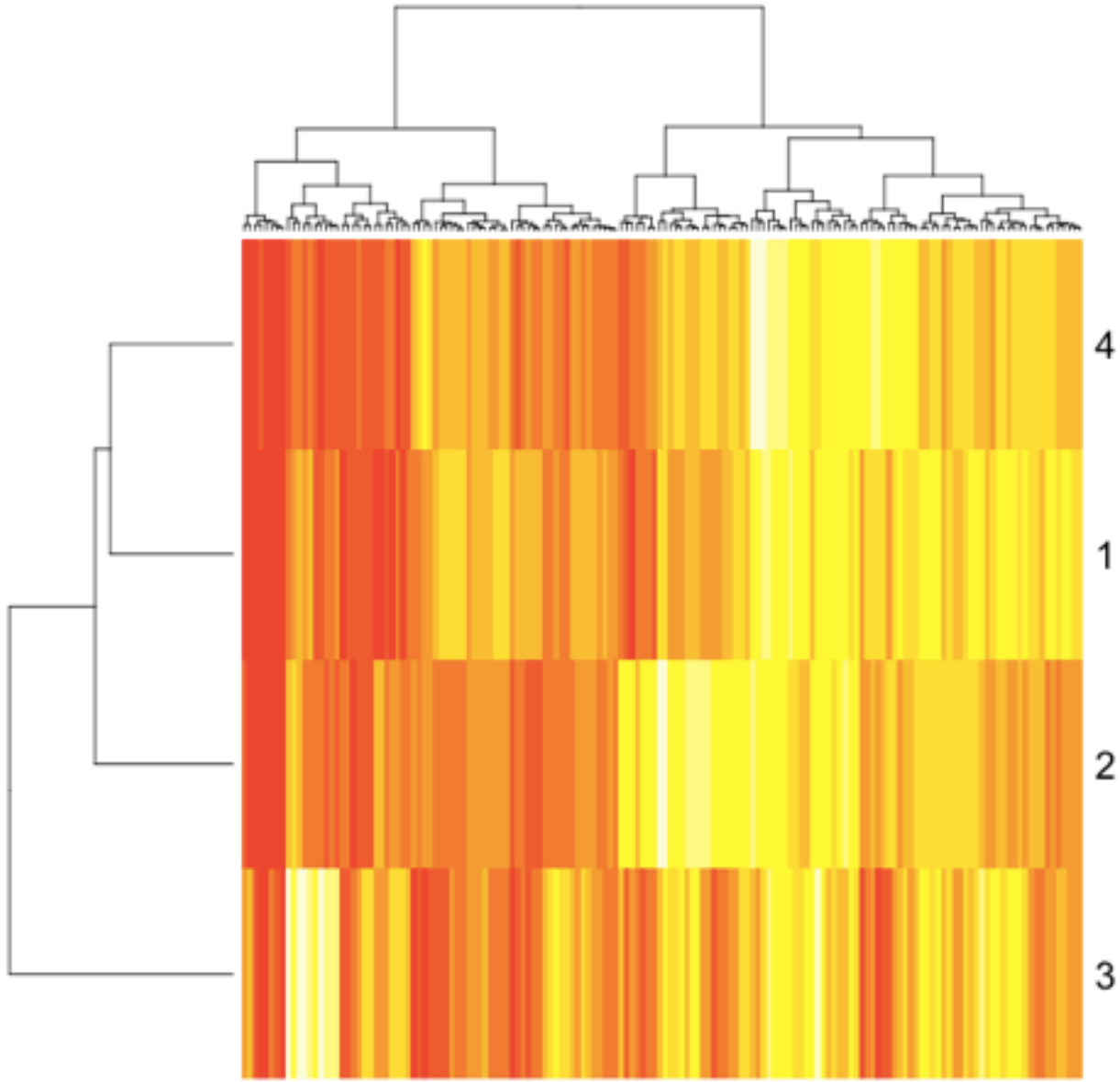
Figure 4. Standards-referenced patents in the citation networks with high betweennness centrality (top 5%). Note: In the left, standards-referenced patents are colored dark red. In the right, patents that reference to different standards are differently colored (3GPP (Blue), IEEE (Red), ETSI (Green), IETF (Yellow), mixed/others (Grey)).

3) Technological clusters along the M2M/IoT trajectory

Table 5. Firms which own patents in each cluster around the earlier M2M/IoT trajectory

Cluster 1 (55 patents)	**Cluster 2 (30 patents)**	**Cluster 3 (31 patents and 6 standards)**	**Cluster 4 (32 patents)**
Trajectory: Ericsson (8407769), InterDigital (8718688)		Standards: 3GPP TS 23.003, TS 23.008, TS 23.060, TS 43.020, TR 22.868, TR 33.812	Trajectory: Apple (8737989)
Samsung (12.7%)	Lemko (36.7%)	Ericsson (37.8%)	LG (28.1%)
Qualcomm (7.3%)	Alcatel-Lucent (6.7%)	InterDigital (10.8%)	Apple (9.4%)
Nokia (7.3%)	Motorola (6.7%)	M2M and IoT (5.4%)	Vodafone (6.3%)
Jasper (7.3%)	AT&T (6.7%)	Apple (2.7%)	Intel (6.3%)
Huawei (5.5%)	Ericsson (6.7%)	Alcatel-Lucent (2.7%)	Cellco (6.3%)

Note: Top five firms were selected based on their share of patents in each cluster. Firms' shares are in parentheses.


4
1
2
3

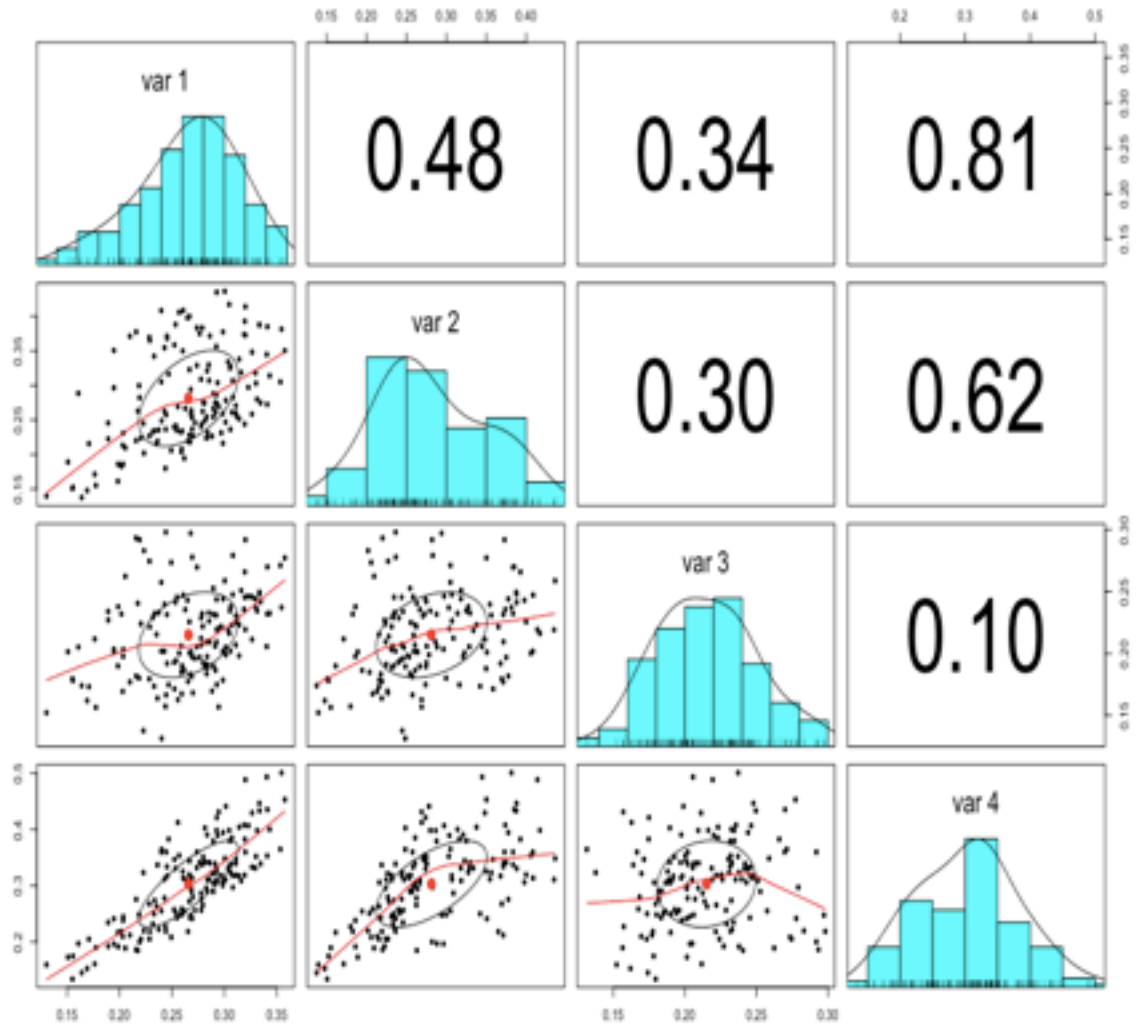

var 1
0.48
0.34
0.81
var 2
0.30
0.62
var 3
0.10
var 4

Table 6. Firms which own patents in each cluster around the latter M2M/IoT trajectory

Cluster 1 (46 patents)	**Cluster 2 (17 patents and 1 standard)**	**Cluster 3 (39 patents)**	**Cluster 4 (10 patents and 5 standards)**
Trajectory: InterDigital (8718688), LG (9137624), Sprint (8638724), HTC (9167470), Alcatel Lucent (9071925)	Trajectory: Huawei (9107226) Standards: 3GPP TS 23.003	Trajectory: Qualcomm (9210527)	Standards: 3GPP TS 23.107, TS 22.367, TS 22.368, TS 23.060, TR 23.888
Nokia (10.9%)	InterDigital (16.7%)	Qualcomm (10.3%)	Ericsson (53.3%)
LG (8.7%)	Huawei (11.1%)	Motorola (7.7%)	Samsung (6.7%)
Alcatel-Lucent (8.7%)	M2M and IoT (11.1%)	Huawei (5.1%)	Alcatel-Lucent (6.7%)
Qualcomm (6.5%)	Fujitsu (5.6%)	Samsung (5.1%)	
Samsung (6.5%)	Ericsson (5.6%)	NTT Docomo (5.1%)	

Note: Top five firms were selected based on their share of patents in each cluster. Firms' shares are in parentheses.

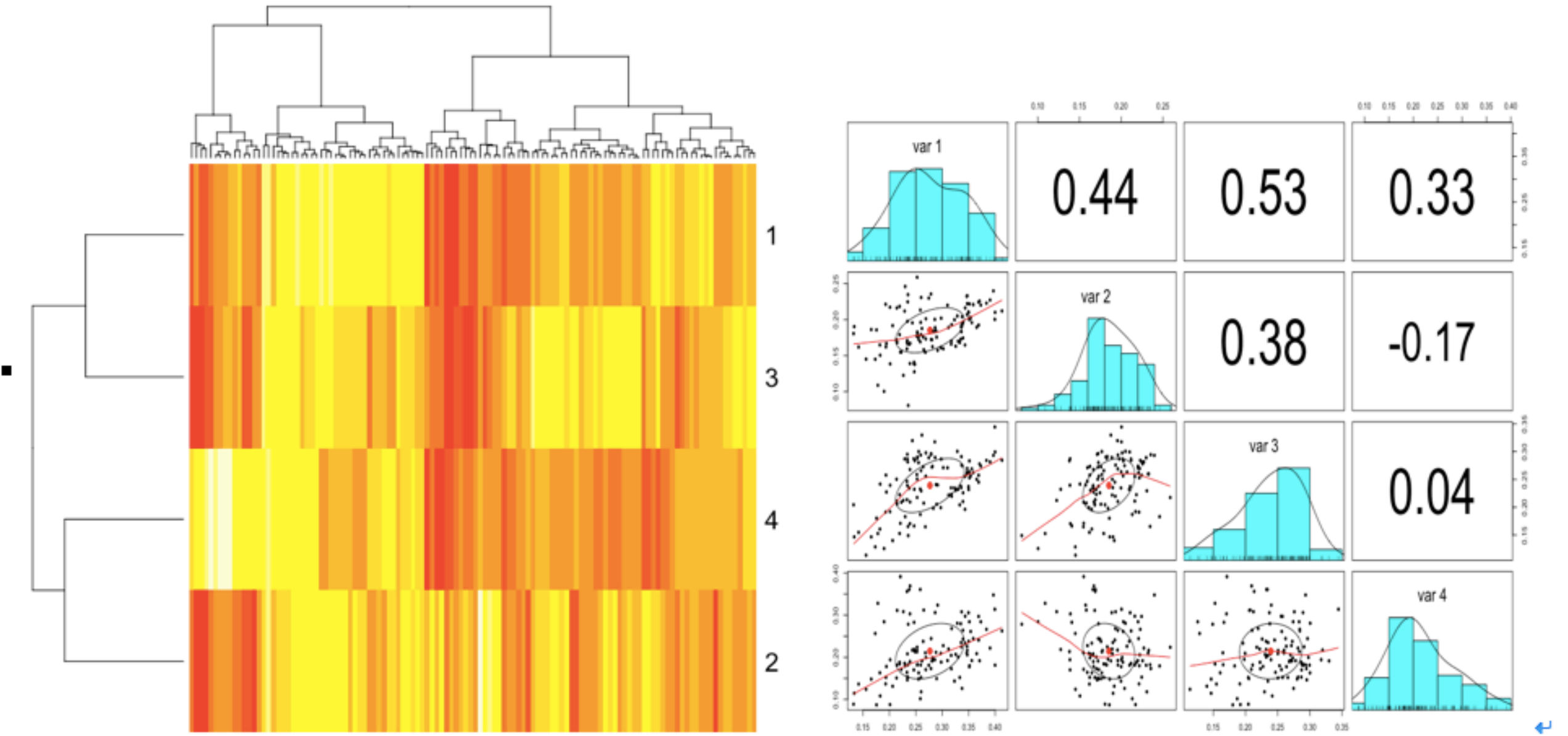


Figure 6. Patent clusters around the latter M2M/IoT trajectory (Left) and correlations between the clusters (Right)

4) Hypothesis test results

Table 7. Empirical test results for the first hypothesis (H1)

	Model 1 (AC)	Model 2 (AC)	Model 3 (AC)	Model 4 (AC)	Model 5 (FC)
Standards	0.598***	0.574***	0.623***	0.357**	0.368**
Backward citations	0.022***	0.017***	0.017***	0.017***	0.006***
Catch-up	-0.285**	-0.575**	-0.482*	-0.108	-0.458**
Year dummy	Yes	No	Yes	No	Yes
LnFirmSize		-0.099	-0.135	0.01	-0.087
LnIP		0.154	0.167	0.05	0.140*
LnR&D		-0.240*	-0.212	-0.091	-0.174*
Constant	0.358	5.022***	5.531***	1.496	3.515***
/Sigma	2.089 (0.099)	1.835 (0.094)	1.828 (0.094)		
Observations	421	343	343	327	343
Log-likelihood	-662.537	-527.890	-525.313		-430.749
Pseudo R^2	0.116	0.055	0.060	0.082	0.065

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. AC: Adjusted Forward Citations. FC: Forward Citations.

Models 1, 2, 3 (Tobit), Model 4 (CLAD), Model 5 (Negative Binomial). Standard errors in parentheses.

Table 8. Empirical test results for the second hypothesis (H2)

	Model 6 (GE)	Model 7 (GE)	Model 8 (GE)	Model 9 (GE)	Model 10 (GE)
Standards	-0.074**	-0.061*	-0.045	-0.085**	-0.068**
Originality		0.225**	-0.678**	0.301**	-0.858*
Originality-squared			0.878***		1.094**
Forward citations	0.011***	0.009***	0.009***	0.006*	0.007***
Catch-up	-0.168***	-0.149***	-0.147***	-0.126***	-0.138***
Constant	0.461***	0.308***	0.484***	0.330***	0.575***
/Sigma	0.265 (0.013)	0.261 (0.013)	0.257 (0.013)		
Observations	253	253	253	253	253
Log-likelihood	-65.389	-62.159	-58.293		
Pseudo R^2	0.277	0.312	0.355	0.116	0.145

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. GE: Generality. Models 6, 7, 8 (Tobit), Models 9, 10 (CLAD). Standard errors in parentheses.

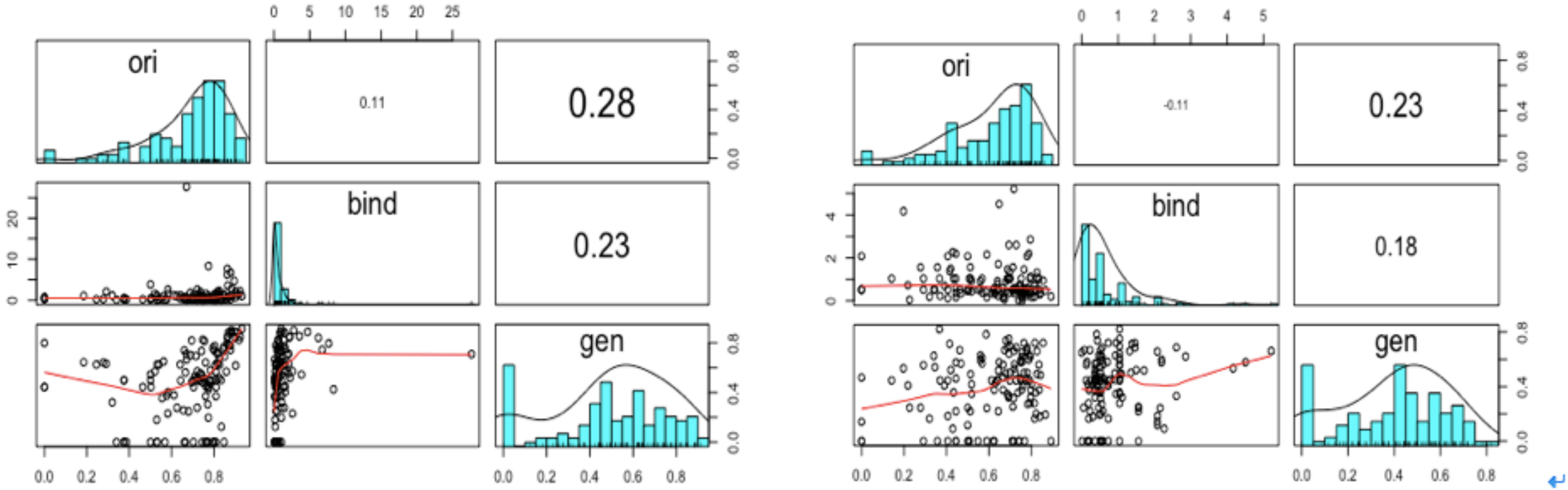


Figure 7. Scatterplots, histograms, correlations for pairwise comparison matrices of originality, binding force and generality. STD=0 (Left) and STD =1 (Right).

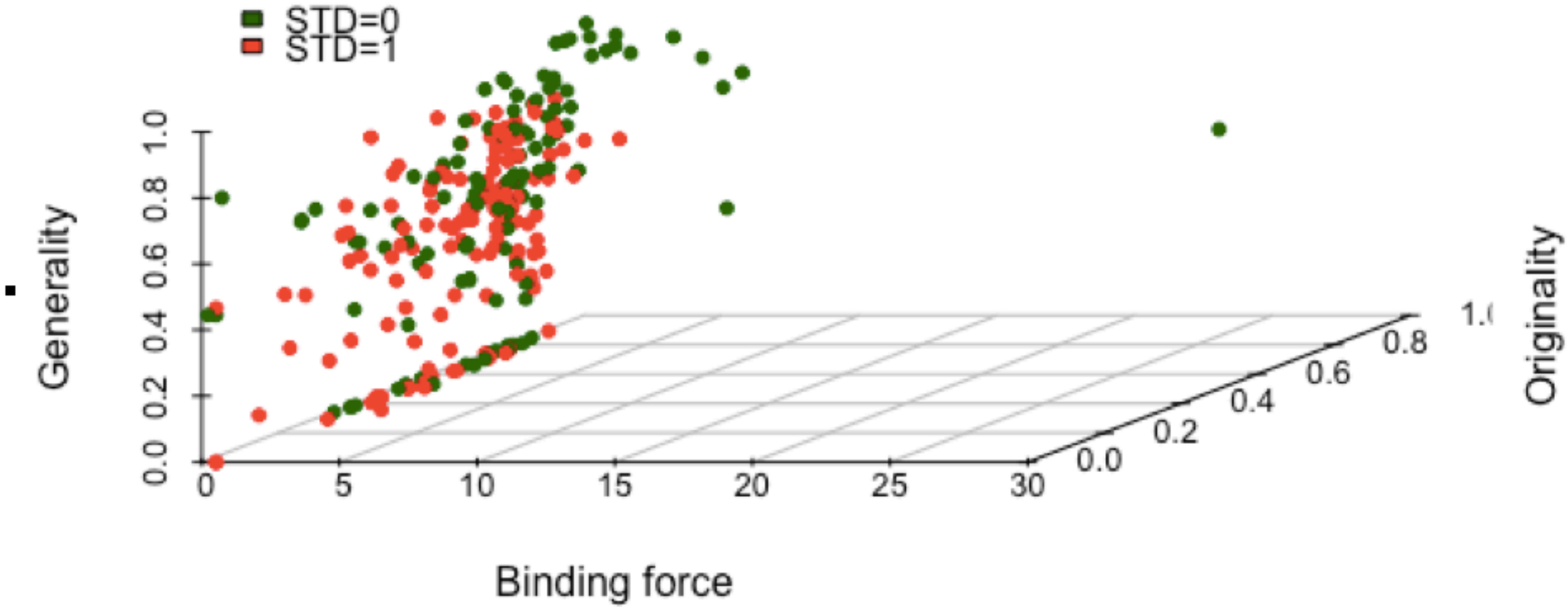


Figure 8. Scatterplot3D of binding force, originality, generality

Table 9. Moderating effect of standards (independent *t*-test)

	Generality (Tobit)			
	STD=0 (n=121)	STD=1 (n=132)	t-statistic	p-value
Originality	-1.682 (0.504)	0.515 (0.406)	3.435	< 0.01
Originality-squared	1.817 (0.466)	-0.195 (0.392)	3.334	< 0.01
Binding force	-0.015 (0.017)	0.055 (0.028)	2.129	< 0.05
Forward citations	0.017 (0.007)	0.005 (0.003)	1.577	> 0.1

STD: Standards. Standard errors in parentheses.

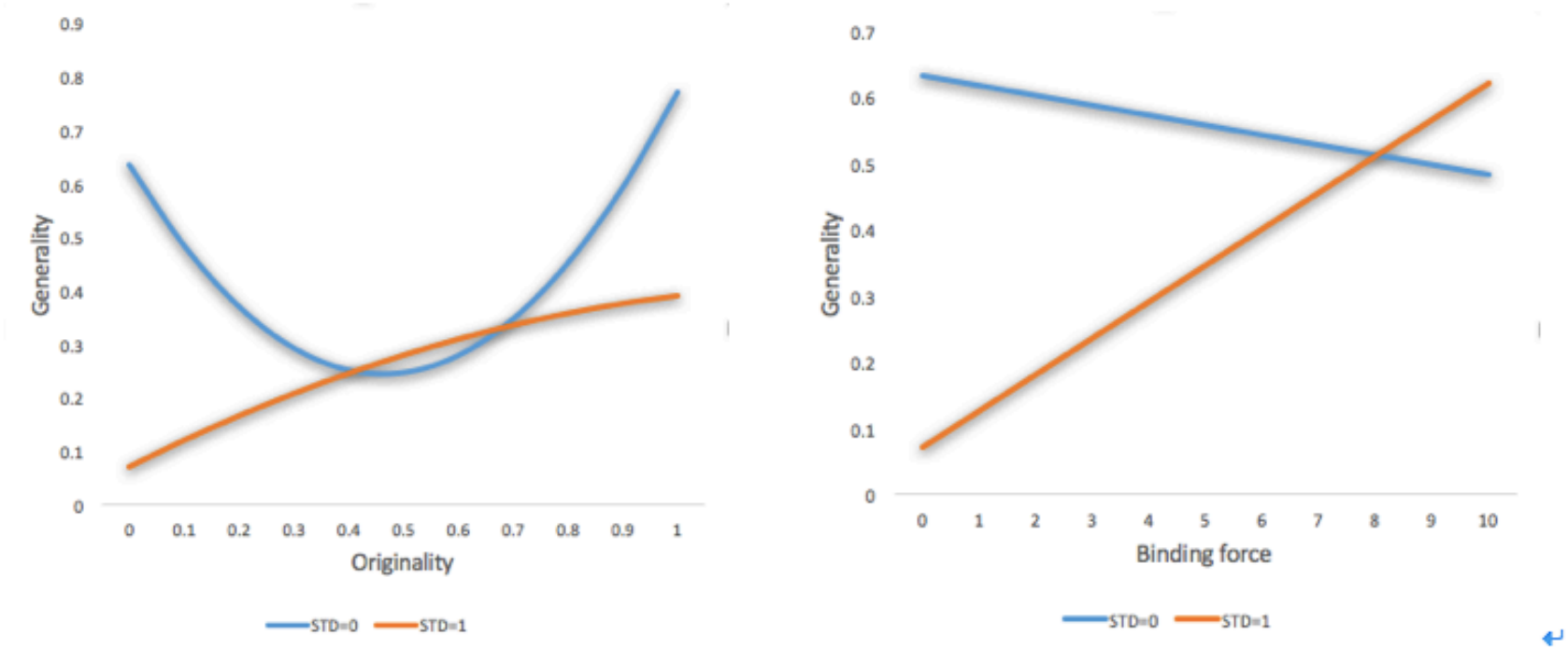


Figure 9. Graphical representation of the moderating effect of standards

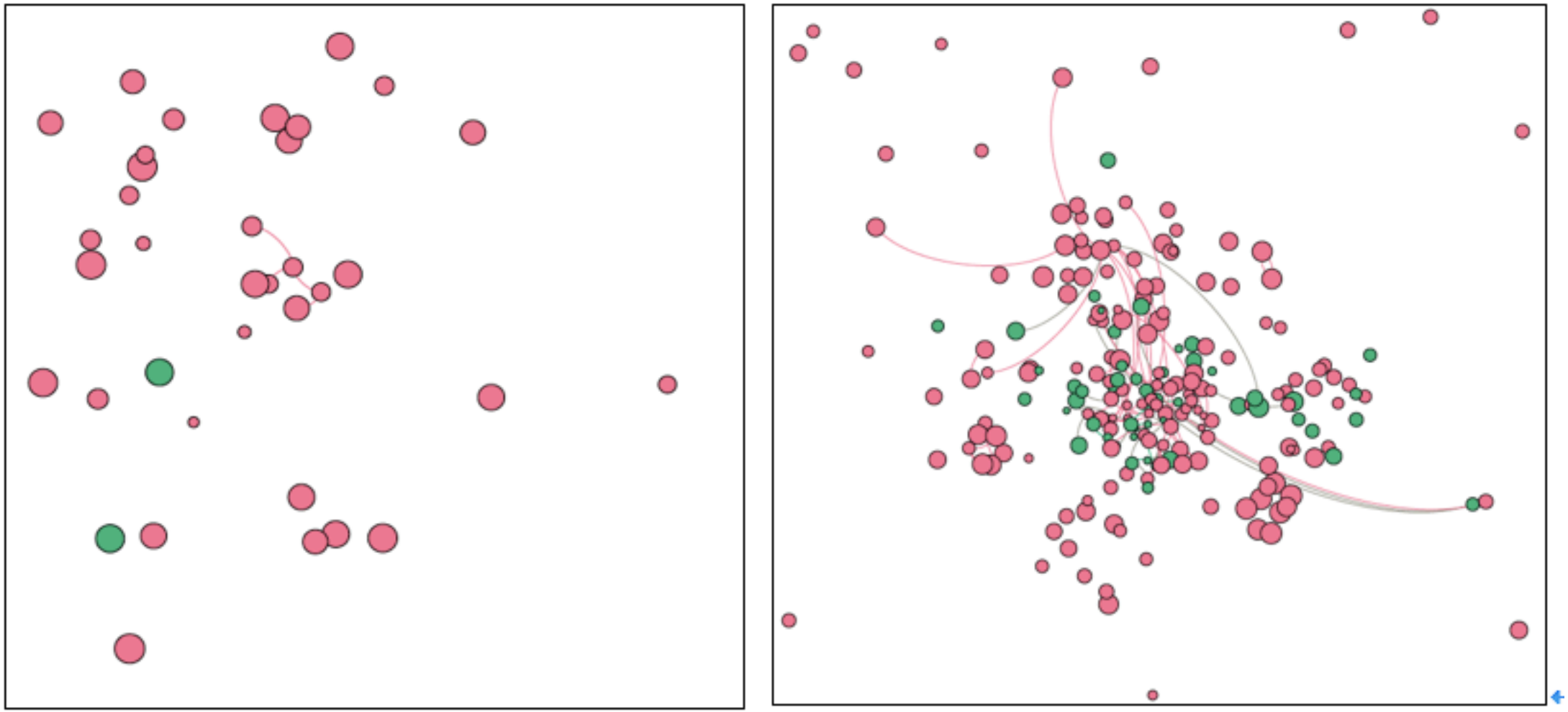


Figure 10. Changes in catch-up firms' M2M/IoT technologies (colored green) in the network of patents with high betweenness centrality (top 5%). Application year 1999-2009 (Left) and 2010-2015 (Right). Node size represents generality.

Discussion: 1) Standards as a driving force of technological convergence

- Technological convergence resulted in industry convergence from vertical integration towards a horizontal structure, which required a high degree of coordination and common interfaces
  - Despite the significant role of standards in industry convergence and value creation, previous research has not yet empirically demonstrated the effect of standards as a driving force of technological convergence

- According to our test results, for the patents that build upon standards, binding forces instead of originality, hold a more significant role in technological diversification.

- It appears that standards serve first as a force of concentration that underpins the construction of a densely connected cluster of M2M/IoT technologies and later as a source of attraction that brings heterogeneous technologies into the cluster

2) Importance of 3GPP standards

- Multiple variants of M2M/IoT standards are currently vying to be selected in the standards-setting committees and become dominant in the market—*iner alia*, 3GPP, ETSI, IETF, IEEE, AllSeen, OIC, Thread, IIC
  - According to our research, 3GPP standards are the one that most strongly shapes the M2M/IoT technological trajectory

- Standardization efforts within 3GPP have focused upon the optimization of core/access networks for M2M traffic and development of high-level frameworks and service capabilities
  - Accordingly, 3GPP TR 22.868, TR 33.812, TS 22.368 and TR 22.888 were released in line with those efforts

- It is noticeable that the M2M/IoT technological trajectory in line with 3GPP standardization efforts has been taking shape in response to well-recognized needs in the market (i.e. a smart, connected product as a service (Porter & Heppelmann, 2014))

3) Two different types of technological clusters (standards-based and platforms-based clusters)

- Bound to a common fate in the face of uncertainty, firms with similar technological capabilities in the strategic groups are likely to create different "strategic blocks" and compete with one another (Nohria & Garcia-Pont, 1991)

- In our analysis of patent text similarity, Ericsson, InterDigital, Samsung, Qualcomm, Nokia, Jasper, Huawei, LG, Alcatel-Lucent are main firms in the same strategic group composed of similar technological capabilities that are compatible with 3GPP standards
  - Interestingly, InterDigital, Huawei, Qualcomm created different technological clusters that were less similar to 3GPP standards along the M2M/IoT trajectory over time
  - It implies that those firms attempted to diversify 3GPP standards-based M2M/IoT technologies, generating new paths of the M2M/IoT trajectory

- Google and Amazon carved out their self-reliant technological trajectory through acquisition of strategically important patents, instead of relying on formal standards
  - This market-oriented approach can be regarded as part of "platform envelopment"(Eisenmann, Parker, & Alstyne, 2011)

4) Standards for a path-creating catch-up and Rise of Huawei

- South Korean and Chinese firms have strategically utilized standards to achieve stage-skipping and path-creating catch-ups, particularly in ICT-related industries (K. Lee & Lim, 2001; Mu & Lee, 2005)

- Our finding confirms that the M2M/IoT technologies of catch-up firms are more concentrated on a standards-based cluster
  - Catch-up firms hold a growingly important role in the creation of a new path along the M2M/IoT trajectory

- It is particularly noticeable that Huawei initiated a path-creating catch-up
  - In our analysis, Huawei's role in the shaping of the M2M/IoT trajectory is growingly influential. For instance, Huawei's patent 9107226 (congestion handing in a communication system) referenced to the IEEE 802.16 standard (WiMax)

- This path of connecting two different standards-based technologies serves as an important part of the M2M/IoT trajectory. This finding stress the significance of standards as a post catch-up strategy

Empirical Analysis:
A case of Huawei and Ericsson's standardization of NB-IoT

Literature Review 1

- *Technological rationality and primacy of power*

  - The stream of literature which centers around **technological rationality as the main determinant of global standards** places emphasis on the institutional structures of standards-setting organizations (SSOs) whose legitimacy derives from the science-based expertise and the governing principles of due process (Loya & Boli, 1999).

  - SSOs institutionalize these foundations of **technological rationality with procedural rules** embedded with the principle of consensus (Schmidt & Werle, 1998).

  - Previous literature on primacy of power underlines that despite the technical language that ostensibly guides the process of standardization, **the essence of rule-making** with distributional implications (i.e. winner/loser generation) is **ultimately political** (Büthe & Mattli, 2011).

  - Some empirical studies (e.g. Weiss & Sirbu, 1990) show that **the market power of firms in a coalition** sponsoring a certain technology is a significant determinant of technological choice in SSOs.

Literature Review 2

- *Strategic importance of alliance and deadline in standardization*

  - Previous literature focused on **strategic alliance as a winning strategy** in standards battles (Cusumano, Mylonadis, & Rosenbloom, 1992; Shapiro & Varian, 1999b)

  - **Deadline is significantly attributed to the different results of the two coordination mechanisms**. Whereas it is highly likely that an early action is made in the bandwagon game, the committee is less likely to reach agreement before the deadline, but if it does so, then the outcome is surely a coordinated decision (Farrell & Saloner, 1988).

  - In the negotiation game where **neither player concedes to the adoption of the other player's preferred standard until a deadline approaches**, firms with high degree of patience tend to have a strong bargaining position (Belleflamme, 2002).

Methodology

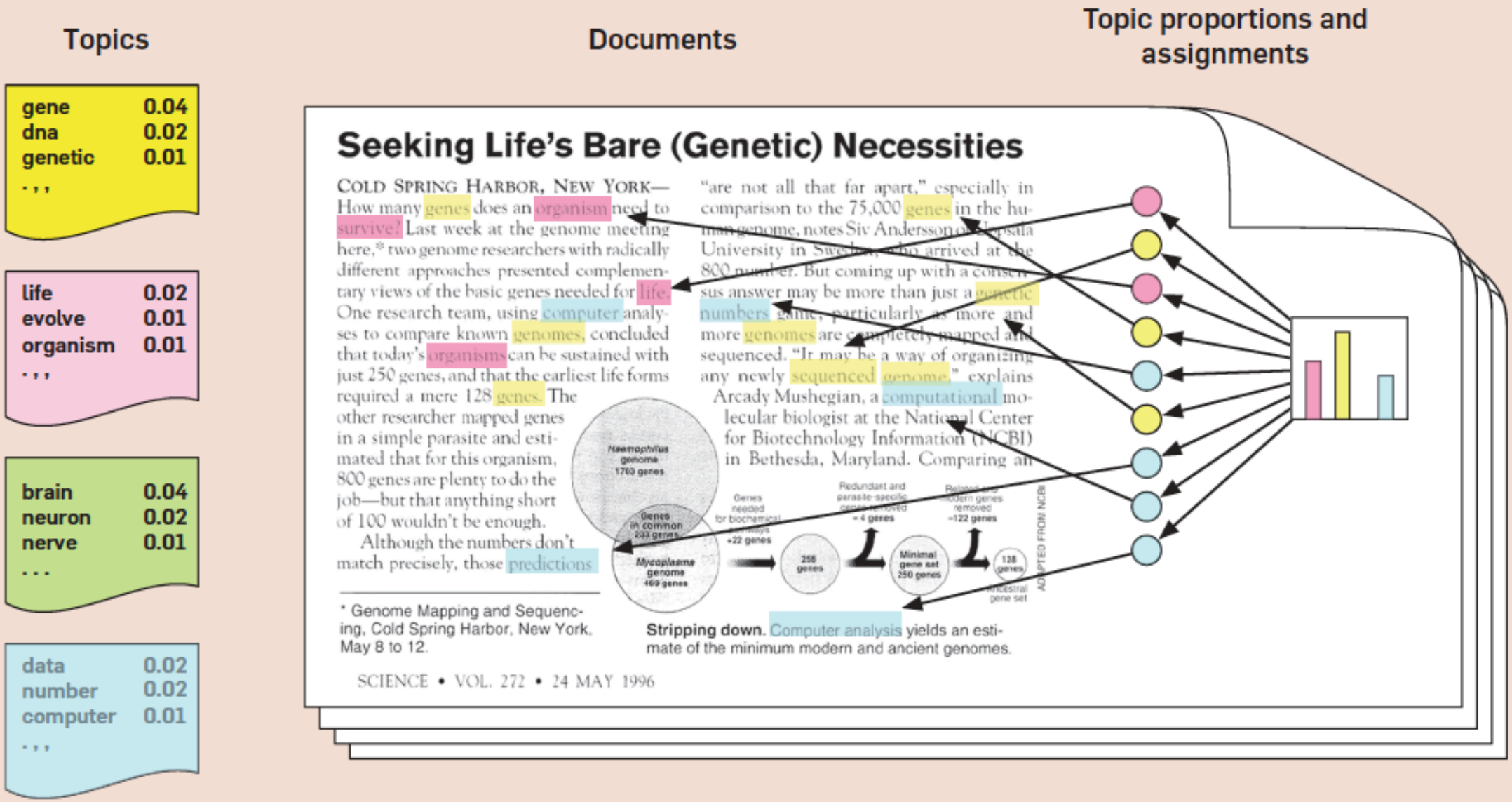
- Mixed method: a case study with the embedded design
  - Both qualitative and quantitative analyses are conducted within a case study research design (Creswell & Clark, 2011) .
  - In this design, quantitative data analysis, in particular, is used to not only provide a confirmatory answer to the main research question, but also to address a secondary question.

- Text data mining:
  - Topic modeling (Blei, 2012)
  - GloVe (Pennington, 2014)

Topic Modeling

- Probabilistic models for uncovering the underlying semantic structure of a document collection based on a hierarchical Bayesian analysis of the words of the original texts
- Unsupervised learning
- Latent Dirichlet Allocation (LDA) (Blei et al. 2003)
- Treats the topic mixture weights as a k-parameter hidden random variable (a multinomial) and places a Dirichlet prior on the multinomial mixing weights

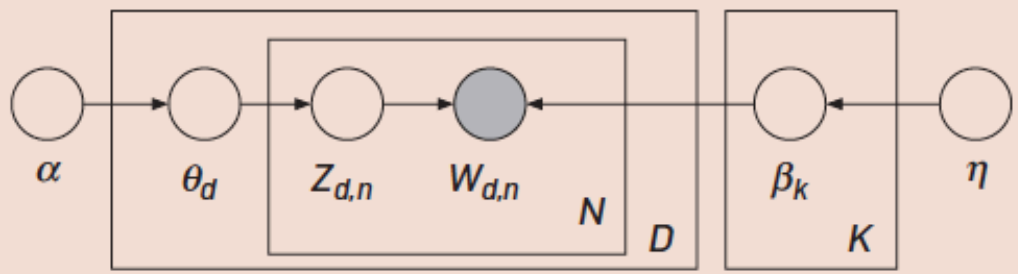
Figure 1. The intuitions behind latent Dirichlet allocation. We assume that some number of "topics," which are distributions over words, exist for the whole collection (far left). Each document is assumed to be generated as follows. First choose a distribution over the topics (the histogram at right); then, for each word, choose a topic assignment (the colored coins) and choose the word from the corresponding topic. The topics and topic assignments in this figure are illustrative—they are not fit from real data. See Figure 2 for topics fit from data.



$$p(\beta_{1:K}, \theta_{1:D}, z_{1:D}, w_{1:D})$$
$$= \prod_{i=1}^{K} p(\beta_i) \prod_{d=1}^{D} p(\theta_d)$$
$$\left(\prod_{n=1}^{N} p(z_{d,n} | \theta_d) p(w_{d,n} | \beta_{1:K}, z_{d,n}) \right). \quad (1)$$

Notice that this distribution specifies a number of dependencies. For example, the topic assignment $z_{d,n}$ depends on the per-document topic proportions θ_d. As another example, the observed word $w_{d,n}$ depends on the topic assignment $z_{d,n}$ and *all* of the topics $\beta_{1:K}$. (Operationally, that term is defined by looking up as to which topic $z_{d,n}$ refers to and looking up the probability of the word $w_{d,n}$ within that topic.)

Figure 4. The graphical model for latent Dirichlet allocation. Each node is a random variable and is labeled according to its role in the generative process (see Figure 1). The hidden nodes—the topic proportions, assignments, and topics—are unshaded. The observed nodes—the words of the documents—are shaded. The rectangles are "plate" notation, which denotes replication. The *N* plate denotes the collection words within documents; the *D* plate denotes the collection of documents within the collection.



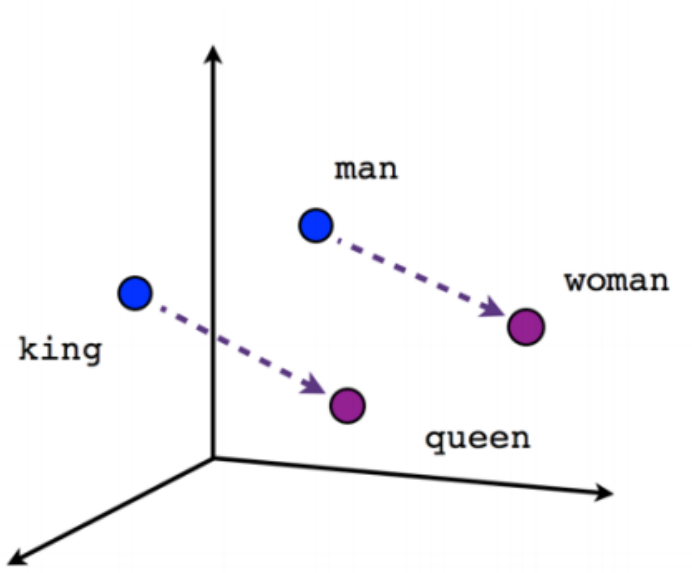
Word vector

- Word vector methods rely on the distance or angle between pairs of word vectors as the primary method for evaluating the intrinsic quality of a set of word representations

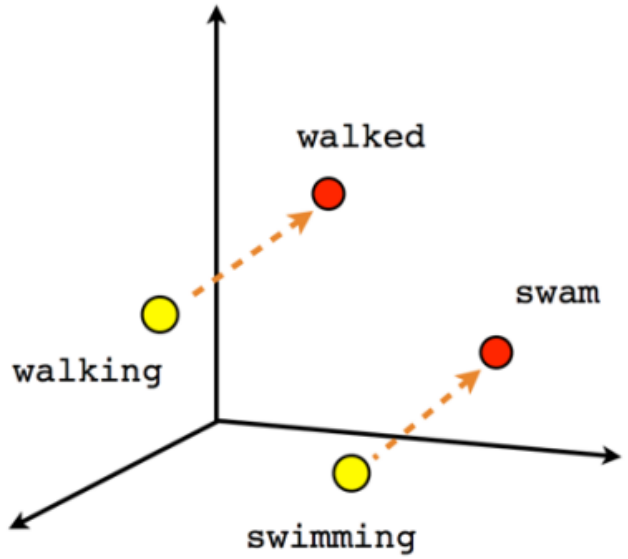
- Mikolov et al. (2013) introduced word2vec, a new evaluation scheme based on word analogies that probes the finer structure of the word vector space by examining their various dimensions of difference.

- For example, “Hello” might be represented as : [0.4, -0.11, 0.55, 0.3 . . . 0.1, 0.02]

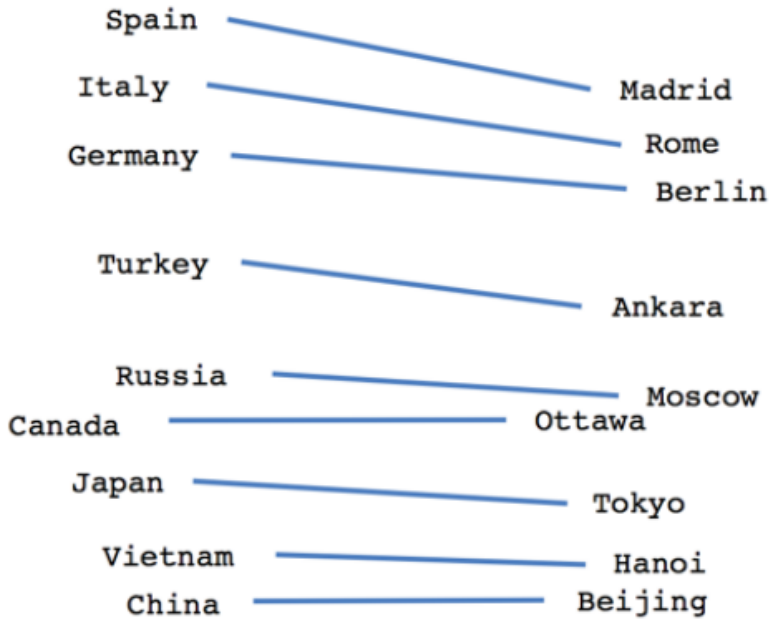
Examples



Male-Female



Verb tense



Country-Capital

vector[Queen] = vector[King] - vector[Man] + vector[Woman]

Global word vector (GloVe)

- GloVe (Paddington, 2014) attempts to overcome the disadvantage of the shallow window-based methods (word2vec) (i.e. they do not operate directly on the co-occurrence statistics of the corpus)

- The relationship of words (semantic structure) can be examined by studying the ratio of their co-occurrence probabilities with various probe words, k (context)

Table 1: Co-occurrence probabilities for target words *ice* and *steam* with selected context words from a 6 billion token corpus. Only in the ratio does noise from non-discriminative words like *water* and *fashion* cancel out, so that large values (much greater than 1) correlate well with properties specific to ice, and small values (much less than 1) correlate well with properties specific of steam.

Probability and Ratio	$k = solid$	$k = gas$	$k = water$	$k = fashion$
$P(k\|ice)$	1.9×10^{-4}	6.6×10^{-5}	3.0×10^{-3}	1.7×10^{-5}
$P(k\|steam)$	2.2×10^{-5}	7.8×10^{-4}	2.2×10^{-3}	1.8×10^{-5}
$P(k\|ice)/P(k\|steam)$	8.9	8.5×10^{-2}	1.36	0.96

than the probabilities themselves. Noting that the ratio P_{ik}/P_{jk} depends on three words i, j, and k, the most general model takes the form,

$$F(w_i, w_j, \tilde{w}_k) = \frac{P_{ik}}{P_{jk}}, \tag{1}$$

where $w \in \mathbb{R}^d$ are word vectors and $\tilde{w} \in \mathbb{R}^d$ are separate context word vectors whose role will

$$F\left((w_i - w_j)^T \tilde{w}_k\right) = \frac{F(w_i^T \tilde{w}_k)}{F(w_j^T \tilde{w}_k)},$$

which, by Eqn. (3), is solved by,

$$F(w_i^T \tilde{w}_k) = P_{ik} = \frac{X_{ik}}{X_i}.$$

The solution to Eqn. (4) is $F = \exp$, or,

$$w_i^T \tilde{w}_k = \log(P_{ik}) = \log(X_{ik}) - \log(X_i).$$

Casting Eqn. (7) as a least squares problem and introducing a weighting function $f(X_{ij})$ into the cost function gives us the model

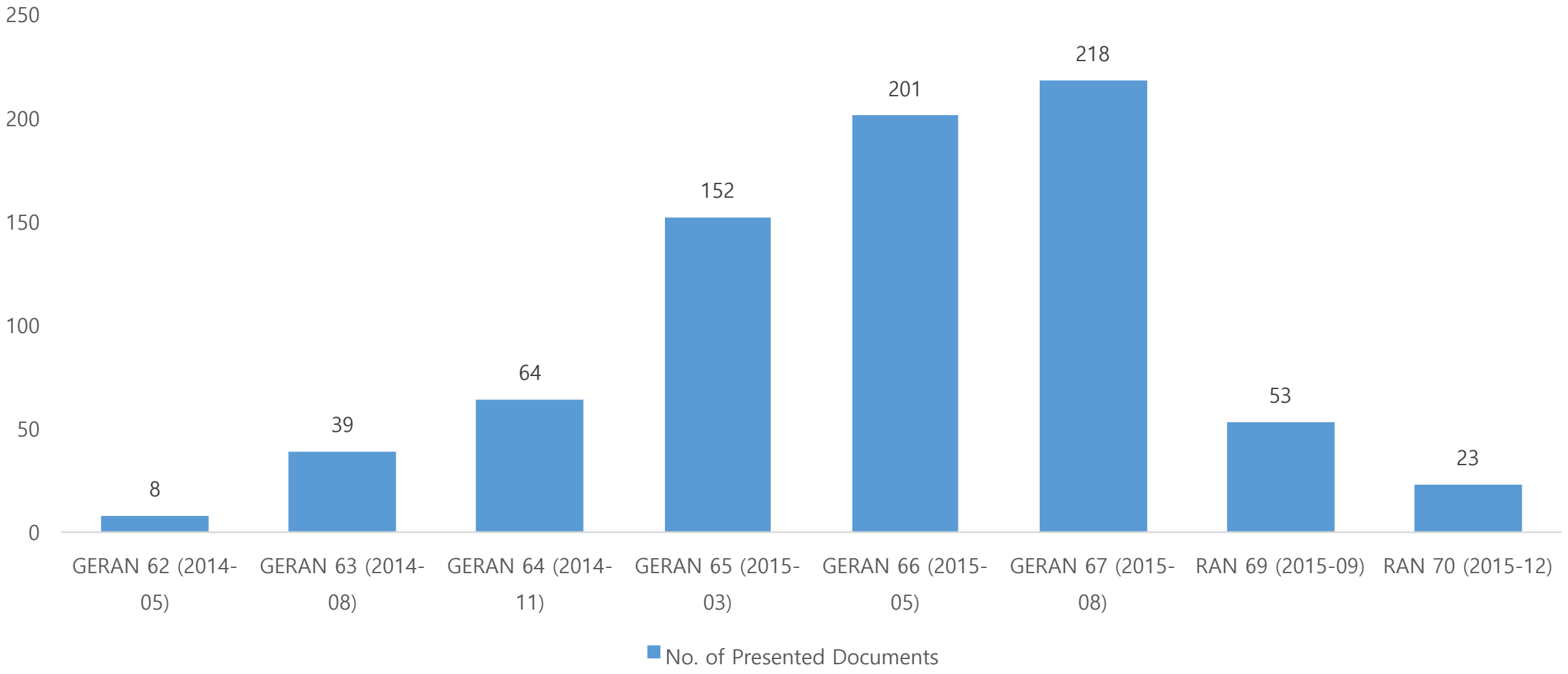
$$J = \sum_{i,j=1}^{V} f\left(X_{ij}\right)\left(w_i^T \tilde{w}_j + b_i + \tilde{b}_j - \log X_{ij}\right)^2,$$

(8)

Data and Software package

- Text Data: 3GPP Reports of GP 62-67, RAN 69-70
- Each report contains the title and summary of documents related to NB-IoT standards and discussions among participants
- 758 presented documents
- Software package: R and text2vec-package ver 0.4

Number of Presented Documents



Text Examples

GERAN 67

Mr. Yutao Sui presented TD GP-150852 **pCR 45.820, Narrowband LTE – Uplink physical layer design** (revision of GP-150792), from Ericsson LM, Nokia Networks.

Comments / Questions: Huawei felt the pCR not justified by a discussion paper, and asked the performance results be provided. Neul also asked for the justification from performance evaluation results. Huawei asked to clarify the number of preamble symbols.

Conclusion: this pCR was revised in TD GP-150965.

RAN 69

RP-151558 NB-LTE - Support of massive number of low throughput devices ZTE, Ericsson, Alcatel-Lucent, Nokia Networks, Samsung, Intel, LG Electronics discussion
Rel-13 -

discussion: Huawei: is this a WG document?
RAN chairman: proponents are trying to provide missing evaluation material here
Vodafone: inband or standalone case?
ZTE: standalone case in this Tdoc
Qualcomm: frequncy reuse 3 not clear, simulated DL channels with UL report?
ZTE: focus on UL traffic capacity which is the bottleneck in our view
Qualcomm: unclear how you know that it is UL limited
Huawei: what's the intention of the Tdoc? to start a GERAN SI
RAN chair: so far let's consider just questions for clarification, we come to detailed discussions later
conclusion: noted

Case Background

- Huawei and Vodafone initiated a study item related to cellular IoT (CIoT) in TSG GERAN in May 2014

- The main objectives of the study are to support low cost/complexity, low throughput, improved indoor coverage and low power consumption with respect to M2M/IoT

- Several technologies were proposed and discussed as candidates for a 3GPP M2M/IoT standard

- 3GPP planned to conclude the study in GERAN 67 and approve one technology for a clean slate standard (non-legacy based) in RAN 69

Standards Competition between Candidate Technologies

- As of GERAN 66 (May 2015), the candidate clean slate technologies were:
  - Narrow Band M2M (NB-M2M): Huawei
  - Narrow Band OFDMA (NB-OFDMA): Qualcomm
  - Cooperative Ultra Narrow Band (C-UNB): Sigfox
  - Combined Narrowband and Chirp Spread Spectrum: Lora
  - Converged (NB-M2M and NB-OFDMA) technology: NB-CIoT

- In GERAN 67, Ericsson and other firms proposed NB-LTE as an alterative to NB-CIoT just before the deadline. This resulted in conflict between Huawei-centered alliance and Ericsson-centered alliance

- In RAN 69, Qualcomm switched from the Huawei side, and proposed a converged solution, NB-IoT

- In RAN 70, Huawei compromised, and NB-IoT was approved as a clean slate candidate for a 3GPP M2M/IoT standard

- **Table 1. Comparison of the physical layer designs of different technologies**

	NB-M2M		NB-OFDMA		NB-CIoT		NB-LTE		NB-IoT	
	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL
Multiple access	FDMA	FDMA	OFDMA	SC-FDMA	OFDMA	FDMA	OFDMA	SC-FDMA	OFDMA	SC-FDMA
Sub-channel spacing	15 kHz	5 kHz	2.5 kHz	2.5 kHz	3.75 kHz	5 kHz	15 kHz	2.5 kHz	15 kHz	3.75 kHz & 15 kHz
Operation mode	stand-alone		stand-alone		stand-alone (later included guard band, in-band)		stand-alone, guard band, in-band		stand-alone, guard band, in-band	

Findings: 1) Impact of temporality, particularly deadline, on the dynamics of technological rationality and primacy of power

- From the beginning of the study item (GERAN 62), technological rationality (performance enhancement) was prevalent in the text of the presented documents and discussions among participant

- However, primacy of power (political alliance supported by economic rationality) became a primary driver of making an irreversible choice right before the deadline in RAN 69

GERAN 65

"Performance (Coverage and Power	"NB-M2M (Physical layer)"	"Discussion (NB-OFDMA)"	"General (presented documents)"	"General (meeting and conclusion)"
CIoT	NB	Asked	GP	Meeting
dB	Layer	Comments	Presented	Conclusion
System	Physical	Questions	EC	GP
Power	M2M	Qualcomm	TD	Noted
IoT	Data	OFDMA	pCR	SA
GSM	Modulation	Felt	GSM	GERAN
Study	Architecture	Band	Ericsson	Document
Performance	Message	Clarify	TR	LS
Cellular	Based	Narrow	Evaluation	Agreed
Coverage	Device	Neul	Revised	Text

GERAN 66

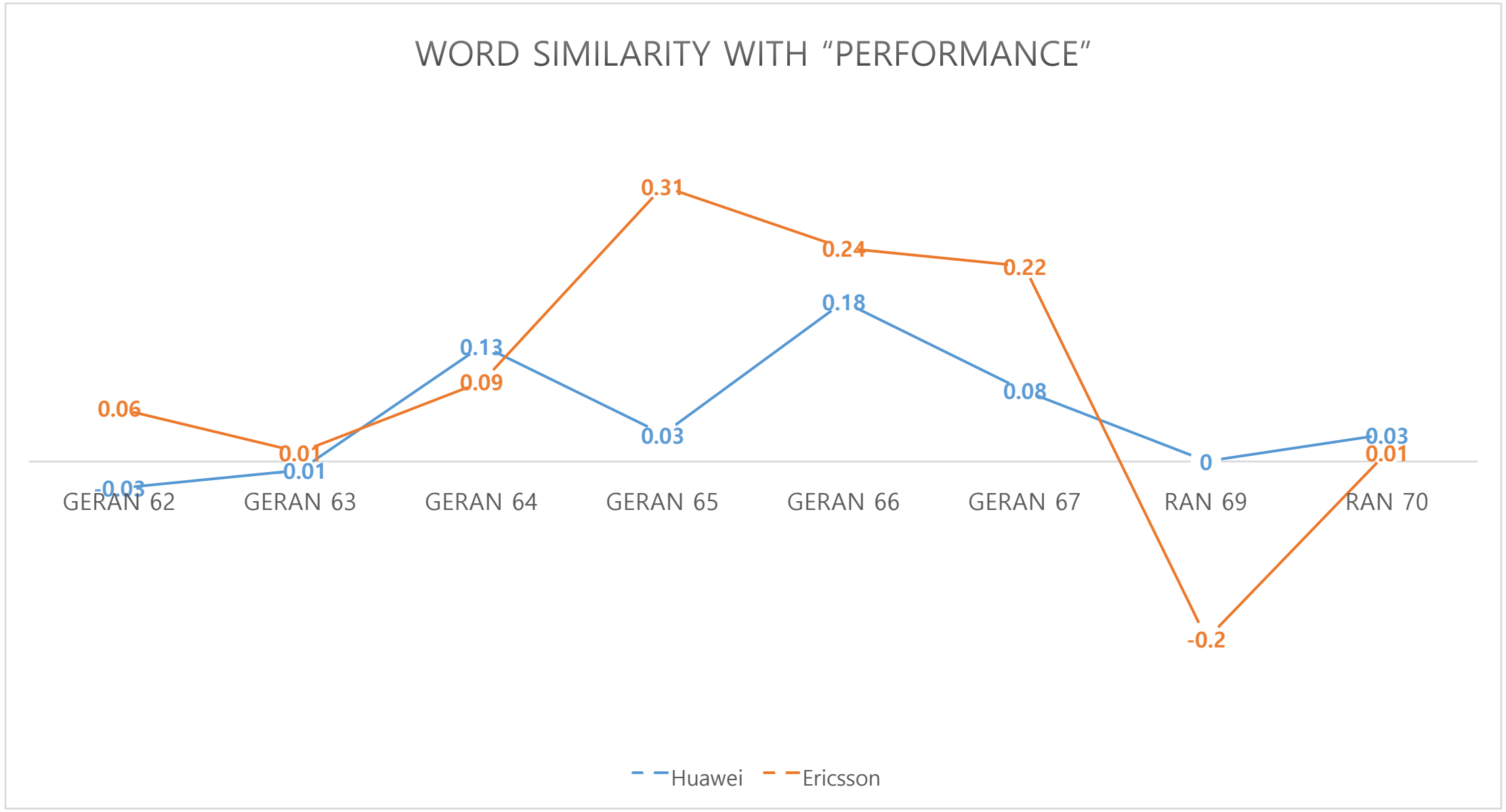
"Performance (Coverage)	"Performance (Power)"	"Discussion (NB-M2M)"	"General (presented documents)"	"General (meeting and conclusion)"
Paging	Power	Comments	GP	GERAN
Coverage	System	Questions	TD	TSG
Device	dB	Asked	pCR	SA
Target	Level	M2M	Presented	RAN
Class	Frequency	NB	Revised	Meeting
Base	Output	Huawei	Revision	Conclusion
Based	Low	Felt	GSM	IoT
Message	dBm	Clarify	Ericsson	Document
Cell	Complexity	Samsung	Agreed	Noted
GSM	Link	Results	Allocated	LS

GERAN 67

"Design of NB-LTE and NB-CIoT"	"Performance (EC-GSM)"	"Discussion (Time)"	"General (presented documents)"	"General (meeting and conclusion)"
LTE	GSM	Comments	GP	Conclusion
NB	Corporation	Questions	TD	Meeting
RAN	Performance	Asked	Presented	GP
CIoT	Alcatel (Lucent)	Felt	pCR	TSG
Design	Legacy	Clarify	Narrowband	GERAN
System	EC	Huawei	Hisilicon	Noted
Solution	Coverage	Discussed	LTE	Document
Slate	Devices	Ericsson	Revision	TD
Clean	Support	Time	CIoT	Plenary
SA	Study	UE	Huawei	pCR

RAN 69

"Political Alliance (NB-LTE)"	"NB-LTE (Physical layer)"	"Discussion (NB-IoT and NB-CIoT)"	"General" (work item)	"General (conclusion)"
Alcatel (Lucent)	UL	WI	RAN	Conclusion
Intel	NB	REL	Chair	Noted
Nokia	LTE	RP	SA	RP
Samsung	DL	IoT	Clean	Internet
ZTE	GSM	WG	Slate	Low
LTE	Operation	NB	GERAN	Things
Shanghai (Bell)	KHz	Discussion	Solution	Complexity
LG	Ericsson	CIoT	Work	Revised
Ericsson	Inband	Band	TR	LS
Discussion	Huawei	FS	Item	Cellular


WORD SIMILARITY WITH “PERFORMANCE”
0.06
0.01
0.09
0.31
0.24
0.22
-0.2
0.01
-0.03
0.01
0.13
0.03
0.18
0.08
0
0.03
GERAN 62
GERAN 63
GERAN 64
GERAN 65
GERAN 66
GERAN 67
RAN 69
RAN 70
Huawei
Ericsson

2) Strategic differences between Huawei and Ericsson, between Huawei and Qualcomm

- Huawei more focused on technological rationality mixed with institutional legitimacy, whereas Ericsson paid more attention to political alliance supported by economic rationality

- Huawei put efforts on meeting the objective of coexistence with GSM (legacy-based), whereas Qualcomm is more interested in OFDMA, which is compatible with LTE

Word Vector (Huawei) – Word Vector (Ericsson)

huawei	hisilicon	modes	serving	envisaged	justified
0.5655841	0.4868025	0.3504852	0.3209782	0.3193955	0.3186856
mimo	timeslot	limited	retransmissions	process	limiting
0.2986774	0.2931421	0.2870230	0.2834877	0.2818105	0.2767477
papr	inform	liu	avoiding	functionality	wenmark
0.2749388	0.2729453	0.2555953	0.2545809	0.2523007	0.2515074
assuming	services	motiv	utran	release	elaborated
0.2472136	0.2460100	0.2453782	0.2449722	0.2415531	0.2412659

Word Vector (Ericsson) – Word Vector (Huawei)

ericsson	alcatel	lucent	bell	mediatek	resolution
0.6109351	0.3637935	0.3432774	0.3289817	0.3282465	0.3261164
optimized	panasonic	determination	ec	corporation	lai
0.3224747	0.3071375	0.2939836	0.2894857	0.2867864	0.2782558
johansson	nokia	zte	sierra	coordinated	handling
0.2744973	0.2727890	0.2710800	0.2611992	0.2610433	0.2609501
nicklas	false	networks	efficiently	contributions	active
0.2539743	0.2510419	0.2479880	0.2476346	0.2458805	0.2408547

Comparison of Ericsson and Huawei's justifications in GERAN 67 and RAN 69

- NB-LTE objectives, proposed by Ericsson:
  - a non-legacy based design from the standpoint of GSM/EDGE
  - to maximize the re-use of LTE physical layer properties such as the multiple access schemes (OFDMA) and tight packing of subcarriers in a way to reduce the device complexity and cost
  - The module cost/complexity between NB-CIoT and NB-LTE is expected to similar with the possibility that NB-LTE could be less depending on stack NRE amortization
  - Reduced technology fragmentation, greater deployment flexibility, greater scalability, higher chances to be completed in the Rel-13 timeline (time to market)

- Huawei's objections and comments
  - The performance and feasibility of in-band deployment for NB-LTE is unclear
  - The UE complexity for NB-LTE has been underestimated
  - Coexistence issues with legacy GERAN and LTE systems
  - Over-optimistic evaluation results due to unrealistic assumptions
  - "NB-LTE is rather a SID than a WID and doubtful that this could be done in REL-13, will require a large amount of parallel resource"
  - Huawei supported the comment from TELECOM ITALIA saying, "[it is] not acceptable the brand new proposal coming at the meeting when the work on CIoT should be finalized"

Word Vector (Huawei) – Word Vector (Qualcomm) + Word Vector (CIoT)

ciot	huawei	gsm	hisilicon	legacy	nb
0.7215211	0.5420647	0.4199012	0.3850704	0.3728404	0.3721487
m2m	coexistence	small	devices	assumptions	simulation
0.3402672	0.3381716	0.3284156	0.2864862	0.2769921	0.2744731
td	observed	si	cell	base	study
0.2703449	0.2678898	0.2664555	0.2651632	0.2646847	0.2634726
iot	evolution	work	slate	impacts	conclusion
0.2560505	0.2509080	0.2420660	0.2418255	0.2394185	0.2366099

Word Vector (Qualcomm) – Word Vector (Huawei) + Word Vector (CIoT)

ciot	qualcomm	ofdma	traffic	consumption
0.6649522	0.5704533	0.3833096	0.3590018	0.3510380
phase	solution	energy	proposed	nb
0.3243519	0.2679196	0.2552366	0.2527690	0.2505582
risk	difference	downlink	normative	study
0.2447476	0.2446247	0.2382136	0.2346866	0.2321950
pcr	corrections	gp	procedures	agreed
0.2318887	0.2318285	0.2280322	0.2266417	0.2249969
systems	enables	selected	slate	miscellaneous
0.2224379	0.2211548	0.2178248	0.2168551	0.2162108

Discussion:

- 1) **In the face of uncertainty, primacy of power takes precedence over technological rationality when participants make an irrevocable choice**

- A Study concluded that “NB-CIoT” and “EC-GSM” met all objectives, whereas “NB-LTE”, as proposed, was incomplete in RAN 69. The Study Item was closed. EC-GSM Work Item was approved on the basis that it met the objectives and the Study Item was closed. Yet despite the fulfilment of the objectives, NB-CIoT was not approved due to a lack of political support

Performance objectives for completed techniques

Performance Objective	Completed techniques	
	EC-GSM	NB-CIoT
Improved indoor coverage (see 4.1.1)	Compliant	Compliant
Support of massive number of low throughput devices (see 4.1.2)	Compliant	Compliant
Reduced device complexity (see 4.1.3)	Compliant	Compliant
Improved power efficiency (see 4.1.4)	Compliant	Compliant
Latency (see 4.1.5)	Compliant	Compliant

Performance Objective	Partially described techniques				
	NB-LTE	NB-M2M	NB-OFDMA	N-GSM	C-UNB
Improved indoor coverage (see 4.1.1)	Expected to be fulfilled	Compliant	Compliant	Expected to be fulfilled	Not compliant
Support of massive number of low throughput devices (see 4.1.2)	Inconclusive/FFS	Compliant	Expected to be fulfilled	Inconclusive/FFS	Not compliant
Reduced device complexity (see 4.1.3)	Inconclusive/FFS	Expected to be fulfilled	Expected to be fulfilled	Expected to be fulfilled	Not compliant
Improved power efficiency (see 4.1.4)	Inconclusive/FFS	Compliant	Compliant	Inconclusive/FFS	Not compliant
Latency (see 4.1.5)	Expected to be fulfilled	Compliant	Compliant	Compliant	Not compliant

- **2) Coordination of economic interests is key to build a strong political alliance**

- A majority of participants in 3GPP have great interests in LTE-related technologies (non-legacy) as compared to GSM (legacy)

- Ericsson's economic reasoning (i.e. cost, scalability, deployment benefits of re-using LTE) was effective in aligning the interests of participants around NB-LTE

Conclusion

- *Empirical and methodological contributions*
  - This study will add empirical and methodological contributions to the **studies of standards and innovation pertinent to technological change**.
  - These findings will contribute particularly to studies **on the role of standards and science as sources of knowledge in innovation and technological convergence**.
  - This attempt is likely to fill a research gap in the broader literature on **standards-setting as a form of power struggle and strategic decisions.**
  - To the best of my knowledge, there has been **no standardization studies that employ a text-data mining-embedded case study method**.

Conclusion

- *Practical contributions*
  - This finding may **resonate with standardization experts** who have been involved in the M2M/IoT standardization from early on.
  - Drawing on patent citations-based and patent text similarity-based clustering analyses, I identified strategic patents and strategic groups, which would **assist firms' decision-makers in developing their IoT technology strategy**.
  - This contributes to broadening the understanding of IoT standardization for catch-up strategists and standardization experts **from the perspective of a post catch-up strategy.**