CTNDCI: Identifying the Political, Legal and Technical Challenges Towards a distributed Nano Data Center Infrastructure

MELANIE HAUSER, LMU Munich, Germany
DIANA IRMSCHER, LMU Munich, Germany
KATRIN KOLB, LMU Munich, Germany
MENGCHU LI, LMU Munich, Germany
KATHARINA RUPP, LMU Munich, Germany
ANDREAS SCHOLZ, LMU Munich, Germany

With the global increase in IP traffic the question of how to provide and deliver data is becoming increasingly important. Monolithic data centers, as they are used today, pose several problems, such as high energy consumption and lack of scalability. An alternative solution mitigating the problems of monolithic data centers has been proposed in the form of a distributed nano data center infrastructure. Research has shown this to be a superior solution considering energy consumption and scalability. However, no widespread solution based on a nano data center infrastructure has been implemented as of yet. In this paper we identify the challenges currently preventing nano data centers from becoming the dominant form of content provision on the internet. By identifying the main challenges nano data centers are facing, steps can be taken to overcome these challenges in a more focused way, leading to a more economic data distribution. We therefore identify the main challenges, categorized in political, legal and technical challenges. We also find that nano data centers are not as energy-efficient as they are supposed to be (under certain conditions). To conclude, for a feasible implementation of a nano data center infrastructure, a number of technical and non-technical challenges have yet to be solved before nano data centers can be considered a realistic alternative to monolithic data centers.

Additional Key Words and Phrases: Green IT; Nano data center; Energy consumption; Security; Availability; Scalability; Data distribution

1 INTRODUCTION

Nowadays, concerns about the environment are increasing and finding alternatives that reduce waste, CO2-emission or energy consumption, is a challenging topic. In order to fight environmental problems, it is essential that sustainable solutions are realized in every possible area. These areas also include internet content provision and storage.

Traditionally, monolithic data centers are used to store and manage today's constantly rising mass of data. This centralized approach, though, consumes huge amounts of energy and especially cooling is a severe issue. To overcome these issues and provide a more energy-efficient approach, de-centralized models have been introduced. Among others, the model of nano data centers was advocated. This kind of data center solution is said to be highly energy-efficient while still providing sufficient content availability and uptime.

Thus, the question arises why no such approach has been realized so far. Also, the media attention towards the topic is quite low, even so the findings presented in the according papers, which will be treated in section 2, are very promising.

Therefore, the purpose of this paper is to identify challenges that prevent the large-scale realization of nano data centers:

- What are political and legal challenges that yet have to be overcome?

Authors' addresses: Melanie Hauser, LMU Munich, Munich, Germany, melanie.hauser@campus.lmu.de; Diana Irmscher, LMU Munich, Munich, Germany, d.irmscher@campus.lmu.de; Katrin Kolb, LMU Munich, Munich, Germany, katrin.kolb@campus.lmu.de; Mengchu Li, LMU Munich, Munich, Germany, mengchu.li@yahoo.com; Katharina Rupp, LMU Munich, Munich, Germany, katharina.rupp@web.de; Andreas Scholz, LMU Munich, Munich, Germany, andreas.scholz@campus.lmu.de.

- What are technical challenges that have yet to be overcome, especially:
  - Are nano data centers really as energy efficient as the previous papers indicate?
  - If so, are the energy savings as high for all use cases?

These questions will be answered in the course of this paper. To achieve this, scientific publications concerning nano data centers, as well as related approaches were researched and compared. Moreover, an interview was conducted with an expert on monolithic data centers, to gain further insight into data center models and real world problems that might not yet have come up or seemed relevant in theory.
At first, related papers are presented. After that, the used methodology is described and challenges towards a distributed nano data center infrastructure are discussed. The challenges extracted from relevant papers rise from a variety of categories. In this paper, though, only political, legal and technical challenges are analysed in depth. After presenting our findings, we will evaluation and discussion them. Lastly we provide an outlook on what future work could be done to help with the decision process of whether nano data centers are a realistic future alternative to monolithic data centers.

2 STATE OF THE ART

Many researchers have already mentioned some challenges regarding nano data centers. Still, they focus more on the positive aspects of them rather than explaining these challenges. For this reason this paper is focusing on identifying these challenges in more detail. In this section, the state of the art on the current research on nano data centers is presented.

2.1 ECHOS

ECHOS introduces a concept for Nano Data Centers that can or should completely replace monolithic data centers [13]. The authors call it a radical solution for data management and provision. According to this concept, so-called "boxes" are set up at the edges of the network, eg. in home gateways (see [16]). These boxes communicate with each other via a peer-to-peer system. The peer-to-peer system as well as the bandwidth is controlled by a central unit, such as the ISP. However, the approach of networking boxes via a peer-to-peer system, and thus providing or sharing content, requires some conditions. So it is first necessary to provide a distributed hosting edge infrastructure. Furthermore, there are also some other problems mentioned. In ECHOS these are listed as follows [13]:

- "Lack of service guarantees due to uncontrolled interface between different applications."
- "Inefficient use of network's and other peer's resources and consequently suboptimal performance."
- "Even if sufficient status information is in place, still P2P is inherently unable to use it as it was designed around selfish user behavior and free-riding prevention mechanism [...]."
- "Absence of security and control make it impossible to guarantee the integrity and security of content."

The problems here are only superficially addressed, and accordingly the solutions to the problems are more general. In this thesis it is conveyed that it is very easy to develop a nano data center platform. The solutions are rather unsatisfactory, and require more investigations.

2.2 NaDa

In the paper from Valancius et al. [17] another Nano Data Center approach called NaDa is proposed. Based on a variant of a peer-to-peer network, NaDa consists of distributed servers, which are managed and controlled by an ISP. According to the authors, devices like DSL or Cable modems can serve as gateways and replace monolithic data centers regarding the use of many Internet services. Their paper, however, only covers video streaming services.

The authors claim that NaDa consumes up to 30% less energy than a traditional data center for this specific use case. The following challenges can be extracted from the paper:

- The ISP needs to invest into gateways with more storage and bandwidth to create a reliable network.
- There is no research into other applications of NaDa (except VoD services).
- The users would have to pay for the energy the gateway consumes. This cost is said to be "not significant", but users might not share this sentiment.
- "[...] each user is assumed to have identical network distance to every other user in a network (this is what would happen on a mid-sized metropolitan area network)." As a consequence, energy consumption and access times could be a lot less promising in rural areas with greater and less evenly spread distances between users.
- The energy savings depend on the number of users, which could make possible users more reluctant to engage in this new technology while NaDa is not yet widespread.

2.3 CATT

Eum et al. present the application scenario CATT [9], the main purpose of which is to decrease delay and disruption for video streaming. In their opinion, there are three main problems, which can be solved individually, but there is no single solution for all of them. CATT is supposed to provide this solution. The first problem is that mobile and fixed-line operators are afflicted with increasing operational cost. The second problem is that mobile users have to accept long delays because of the distance to their providers. Furthermore, mobile users suffer from service disruption and disconnections during handover. With CATT, ICN nodes can work as independent content providers, which removes the latency and multiple hops.
A prototype of the system has been developed, but the idea has not been fully developed. The authors point out that during development special attention has to be given to the protection of not only the data, but furthermore of a malicious network resource abuse.

3 CHALLENGES TOWARDS A DISTRIBUTED NANO DATA CENTER INFRASTRUCTURE

In the following sections, the methodology is described, whereafter political, legal and technical challenges are presented.

3.1 Methodology

To identify the challenges towards a distributed nano data center infrastructure we used two types of methods. Firstly, our research consisted of studying previous work and papers. We apportioned work we found among the team members. Every team member extracted the challenges, which were stated in the papers, and analyzed them for our work.
The second method that was used was conducting a qualitative interview with an expert. For this interview we chose an expert on nano data centers, who works for the Leibniz Supercomputing Center.
We purposefully excluded other techniques from our methodology. Observations and experiments simply did not fit our research topic and its current research status. Online surveys, questionnaires, and interviews with pedestrians were also excluded, because the topic demands a certain background knowledge and understanding. This knowledge and understanding cannot be expected from citizens.
Our results from the research and interview are stated in the next sections.

3.2 Political and legal challenges

Due to its distributed nature a nano data center infrastructure will face additional political and legal challenges when compared to a traditional monolithic data center infrastructure. In the following sections we will discuss important political and legal challenges. We acknowledge that there will be many more challenges to be overcome in these fields. However, most of these will arise during implementation and are therefore difficult to predict. Hence, we restricted ourselves to challenges of each field which will certainly have to be overcome.

3.2.1 Political challenges. Once the decision to transition to nano data centers has been made the question arises of who will be responsible for that infrastructure. Considering that nano data centers would likely be integrated into today's modems, with which each household connects to their internet service provider (ISP), the ISP would be an obvious choice. The ISP already has knowledge of their network and is also already distributing modems. However, this raises other challenges:

How to distribute data between ISPs?
Most internet users only have one ISP they use to connect to the internet. As not every ISP can be expected to store all of the worldwide information that is currently stored in monolithic data centers, a solution has to be found to access data which is not currently provided by the ISP a person is connected to. This might include international partnerships which further increase the challenge to introduce political policies for such cooperations.

How to ensure net neutrality?
If ISPs are not only responsible for providing bandwidth but also for providing data, a conflict of interest might arise as to which data to provide with which priority. Especially when considering cooperations between different ISPs as mentioned above, an ISP might want to prioritize data deliverance to its own customers before servicing those of other ISPs. To ensure net neutrality, policies have to be introduced to ensure the same quality of service for each customer across different ISPs.

If these challenges prove too difficult to overcome, ISPs might not be the best choice to manage nano data centers. In this case a third party would have to be introduced for managing the nano data center infrastructure. By having an ISP independent third party the issue of net neutrality would be greatly reduced. However, the challenge on how to distribute data across different ISPs would be unaffected. Additionally the question of how to distribute the management software of the nano data center infrastructure onto ISP dependent hardware would arise.

3.2.2 Legal challenges. Legal regulations will pose challenges on the way to a distributed nano data center infrastructure. Some of these regulations are already in effect, others will yet have to be introduced to deal with the new state of the art. In this section we will introduce one challenge each as an example of what kind of legal challenges can be expected. As before, we acknowledge that there will be many other challenges to be overcome.

[4] mentions as key problem for using public cloud computing the geographic location (jurisdiction) of data. Privacy laws govern how data is stored and who may access that data. There are many different laws. Transborder data laws govern where data can be stored. Moving data between different jurisdictions is called transborder data flow and can be difficult or illegal. This depends on content type or country of origin. This also intimidates cloud providers, so that they build redundant datacenters in each needed jurisdiction. Some jurisdictions allow transborder data crossing, when the other jurisdiction provides at least equivalent levels of protection. The amount and variety of these laws hamper the extension of cloud computing or can even affect the implementation of nano data centers.

The European Union Data Protection Directive (EUDPD).
[4] reveals, that holding personal data from an EU citizen in other countries than EU members is forbidden by the EUDPD, except they can provide appropriate protection. Switzerland, Argentina, Canada and the Isle of Man

can provide the required protection. This is a very limited region, but in special cases data can also be stored in the United States. In this case the United States Safe Harbor rules play an important role.

The United States Safe Harbor Rules.
With this law and an associated certification companies in the US can process or store EU data. If a company wants to be certified, it has to apply and agree to the requirements. But there are also limitations like the fact that the company has to be under the jurisdiction of the Federal Trade Commission. The inconsequent legislative facts and the complicated laws hamper the idea of global monolithic datacenters and also the idea of distributed nano data centers. [4]

Conflicting Legislation: The USA PATRIOT ACT.
Obtaining personal data of foreign companies and persons is allowed by this Act, when the data is stored in the US. Therefore, EU companies, which store data in the US, should reckon that the US may read their data. If an US company stores data in the EU, then the Act gives the US also the right to collect private data. This leads to mistrust, insecurity and does not support the idea of a global-scale datacenter but rather to distributed datacenters. [4]

As pointed out in the previous sections, the current legal situation is complicated and also leaves gaps for uncertainty or mistrust. On the one hand, the laws do not support the introduction of global monolithic data centers, but on the other hand they also do not support the use of nano data centers and a cross-border distribution of data. Global distributed nano data centers could provide greater reach and more opportunities for efficient data storage, distribution and delivery, but this would require a legally secure solution for all involved parties. But even in the future there will be laws that could hinder the idea and implementation of nanodata centers.

General Data Protection Regulation (GDPR) of the EU.

> Wenn ich [...] personenbezogene Daten auf [...] verteilten Systemen speichern will, dann könnte ab 25. Mai nächsten Jahres einer, der jetzt in den Daten gespeichert ist, verlangen: "Wo sind denn meine Daten überall?". [...] Also da sehe ich schon noch Sachen wo ich sage, mit so verteilten Systemen und Rechenzentren wird das relativ schwierig, [...] was nicht heißt, dass das nicht funktioniert, was aber vielleicht heißt, dass der Aufwand das zu realisieren mehr ist als [...] wenn man es bei uns macht [15].

On May 25th, 2018 the GDPR EU regulation will come into affect. It states, that any individual has the right to request information about data, which can personally identify them. This includes information about where this data is stored, whether it will be transferred to other entities, how long it will be stored, for which purpose it is stored and others. It also provides an individual with the right to request access, rectification and erasure of this data as well as restricting further processing of that data [7]. Having a monolithic data center in one physical location makes these requirements easier to fulfil. With a distributed infrastructure however, keeping track of where, what kind of data (personal or not) is stored, (including all its backups) is challenging. Additionally, when considering non EU cooperations of nano data center infrastructures, the organisation handling the personal identifiable data has to ensure that the same regulations as mentioned above are in effect in the country the data will then be stored in [8].

Liability for data stored on a nano data center?
Considering that every household that is part of a nano data center infrastructure would physically store some part of the data of the whole system, the question of liability for that part of the data arises. If illegal data is stored on ones own nano data center, can one be held accountable? This problem relates to the "Störerhaftung" (Breach of Duty of Care) regulation in Germany, which, until recently, made operators of open wireless networks

accountable for illegal activities performed by users of that network [14]. As there is no standardised European or worldwide regulation yet, this will pose a challenge for operators of future nano data center infrastructures.

3.3 Technical challenges

While nano data centers are motivated by the energy consumption problem [17], current research reveals that the advantage of the nano data centers in energy efficiency relies on certain technical foundations. In the following chapters, this energy consumption problem and its technical challenges are discussed. Similar to the political and legal challenges, further issues will arise during the development process of nano data centers in the field of technical challenges, which are complicated to predict. The following aspects, however, need to be closely looked at.

3.3.1 Energy Consumption Model for Nano Data Centers. To give an overview of the technical challenges towards nano data center development, we first need to figure out the energy consumers of the nano data center applications.

Considering the nano data center (NaDa) platform proposed in [17], users will host tiny managed nano servers on their end-user devices such as Triple-Play gateways and DSL/cable modems, and communicate with each other following a Peer-to-Peer (P2P) philosophy. Thus, suppose a user (client) wants to access the content stored in a nano server hosted by another user (manager), the energy consumption for this process consists of [11]:

- the energy consumed by the client for requesting the content, denoted as E_{req};
- the energy consumption of the content transportation process, denoted as E_{trans}; and
- the energy consumed by the manager for storing the content and processing the request, denoted as E_{serv}.

If we denote the total energy consumption as E_{total}, we can derive the following formula:

$$E_{\text{total}} = E_{\text{req}} + E_{\text{trans}} + E_{\text{serv}}. \tag{1}$$

To detail the formula from technical aspects, we need to understand the internet protocol (IP) network. [2] modeled the IP network as the combination of three domains: the access network, the metropolitan and edge networks and the core network. For centralized data center applications, [2] visualized the IP network model as shown in Figure 1. The access network connects each end-user to the metropolitan and edge network, which serves as the interfaces to the core network. Centralized data centers are usually directly connected with the core network, but for nano data centers, since nano servers are hosted in end-user devices, the data has to traverse the access network twice [10].

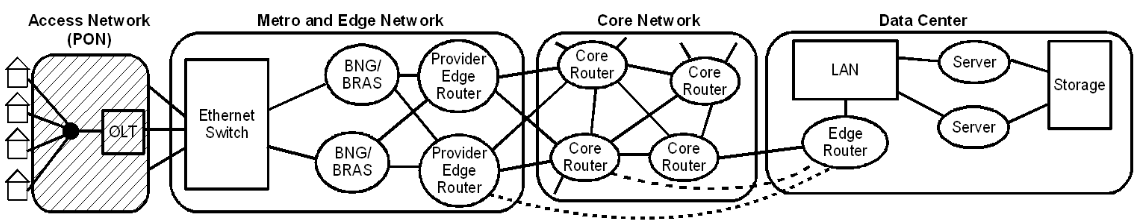

Fig. 1. IPTV network model for centralized data centers [2]

We can now detail formula (1) and adapt it to the energy consumption model proposed in [11] as the following:

$$E_{\text{req}} = E_c + E_{\text{access}}, \tag{2}$$

$$E_{\text{trans}} = E_{\text{edge}} \cdot h_{\text{edge}} + E_{\text{core}} \cdot h_{\text{core}}, \tag{3}$$

$$E_{\text{serv}} = E_{\text{access}} + E_m, \tag{4}$$

where E_c represents the energy consumed in the end-user device of the client, E_{access}, E_{edge}, and E_{core} represent the energy consumed in the access network, edge network and core network, respectively, h_{edge} and h_{core} represent the number of hops in the edge and core networks, and E_m represents the energy consumed in the end-user device of the manager.

In the following, we will introduce three technical challenges that we regard as fundamental and argument our selections with respect to the proposed energy consumption model. These challenges are: the activation of nano servers; the selection of the access network that the nano servers are attached to; and the trade-off between the distance among nano servers and the number of data replications.

3.3.2 Activation of Nano Servers. A nano data center platform is constructed with end-user devices as nano servers. We refer a nano server as *active*, when it is on and the user is accessing the nano data center service, and we refer a nano server as *idle*, when it is on but the user is not accessing the nano data center service. Whenever a nano server is on, no matters it is active or idle, it consumes energy. [17] proposed a thorough study on how the activation status of nano servers affects the total energy consumption. [17] denoted the active time of a nano server as t_{act} and the idle time of the nano server as t_{idle}, and introduced a coefficient R that represents the ratio of the active time of nano servers to the whole duration when nano servers are on:

$$R = \frac{t_{\text{act}}}{t_{\text{act}} + t_{\text{idle}}}. \tag{5}$$

As proposed in [17], R is involved in the calculation of both E_c and E_m in the energy consumption model. As a result, the energy consumption of nano data centers correlates with R as shown in Figure 2, where five different active time ratios (0.01, 0.05, 0.2, 0.5, 1) are chosen for comparison, and the energy consumption of a centralized data center is also shown as a reference. We can see that the energy consumption of nano servers increases as the active time ratio decreases, and when the ratio is larger than 0.2, the energy consumption of nano servers surpasses the energy consumption of the centralized data center, i.e. the nano data center becomes less energy efficient.

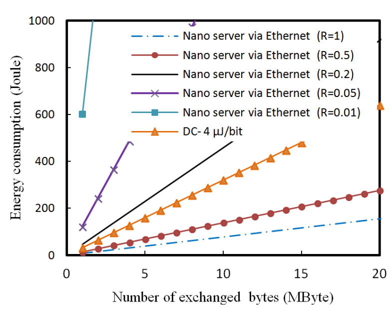

Fig. 2. Energy consumption of nano servers with different active time ratio, and of a centralized data center [17]

A disappointing fact is that we cannot simply assume the active time ratio R to be higher than 0.2 most of the time. Taking the widely-used video delivered by Internet protocol (IPTV) as an example: according to [17] and [5], the IPTV user activity shows large variation throughout the day, as shown in Figure 3. Even the in the peak hour, fewer than 20% of customers are active (i.e. $R < 0.2$); as for in the midnight, less than 5% of customers are active (i.e. $R < 0.05$). On average, the active ratio R is around 0.07, which means that if all nano servers are on in the whole day, it is energy **in**efficient to apply nano data centers.

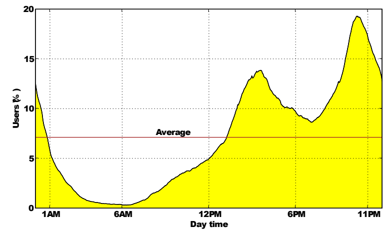

Fig. 3. User activity of the IPTV service [17]

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Therefore, to make a nano data center platform energy-efficient, it is necessary to increase the active time ratio. From our view, a possible solution is to turn off the nano server time to time to reduce the idle time of the nano servers. But for the nano servers attached to DSL-modems or other functional devices, such as the NaDa model proposed in [17], turning off nano servers can lead to side-effects on the usage of other internet services of users, and thus the implementation of this solution requires further study. Another possible solution is to modify the applications for the nano data center, such as running multiple applications that have different peak hours, aiming to maximize the active time of the nano servers. So far we are unaware of any research tackling these problems, and thus we list the activation of nano servers as one of the four technical challenges towards nano data center development.

3.3.3 Access Network. As discussed in Section 3.3.1, the access network connects nano servers to the edge network. According to the analysis proposed in [10] and [11], the power consumption of the access network needs to be counted twice for nano data centers, i.e. E_{access} needs to be counted both in E_{req} and E_{serv}. Thus, the energy efficiency of the access network has a large impact on the energy efficiency of the nano data center platform.

The energy consumption of the access network has been studied in [11] and [3]. Both studies refer Passive Optical Networks (PON) as energy-efficient access networks, and indicate that wireless networks (WiMAX [3], 4G, WiFi [11] are relatively energy-inefficient. Figure 4 shows a comparison of energy consumption between nano data centers using different access networks and centralized data centers with different energy consumption values, where the curves for GPON and Ethernet almost overlap, and the curves for WiFi and centralized data center with $20\mu J$/bit almost overlap. We can see that different access networks result in huge difference of energy consumption, and nano data centers attached to energy-inefficient access networks consume even more energy than centralized data centers.

For nano data centers, since each nano servers is possessed by an end-user, it requires further study on the access network that these end-users may or may not use, before one can determine whether the implementation of nano data centers can save energy or not.

Another concern regarding the access network of nano data centers is the trade-off between energy consumption and the access rate. Figure 5 shows their correlation from two aspects. As shown in the left figure, for a single user, the power consumption increases with the average access rate, and as shown in the right figure, the energy per bit decreases with the average access rate. For the two relatively energy-efficient access networks – Point-to-Point optical access network (PtP) and PON, their performance show different trends with the increase of the access rate. While PON is more energy efficient for a low access rate, it consumes more energy than PtP when the access rate surpasses 300Mb/s. Thus, it also requires further study on the selection of the access networks with respect to the expected access rate.

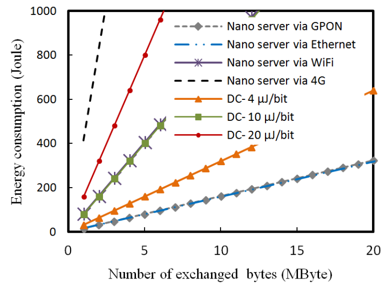

Fig. 4. A comparison of energy consumption between nano data centers using different access networks and centralized data centers with different energy consumption values [17]

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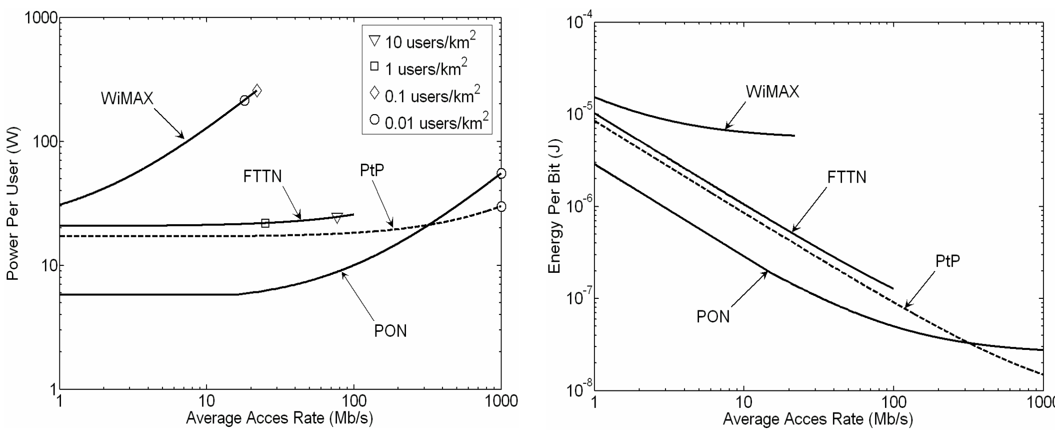

Fig. 5. Power consumption per user for different access networks and energy per bit of different access networks [3]

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3.3.4 Trade-off: Distance and Replication. The energy consumption of the data transmission process (E_{trans}) in nano data center platforms is dependent on the number of hops in the edge (h_{edge}) and core networks (h_{core}), as mentioned in (4) in Section 3.3.1. [11] estimated the average number of hops in the edge and core networks to be 3 and 5, using *traceroute* from end-user devices to WordPress [1] servers. The number of these hops can be understood as the distance between the end-user requesting data and the end-user hosting the corresponding data. Regarding the location of the communicating end-users, the number of hops shows large variation: for non-local users, [11] measured h_{edge} and h_{core} as 3 and 8; and for local users, h_{edge} and h_{core} are measured as 1 and 2. Figure 6 shows the energy consumption of the the core and edge networks for the data transmission between local and non-local users, and compares them with the centralized data center. We can see that if an end-user accesses data from a non-local nano server, the energy consumption of the edge and core networks can be even higher than accessing data from a centralized data center.

A natural solution to reduce or balance the data transmission distance is to add data replicas [10] [2]. However, while data replication can be beneficial to the energy-efficiency in the transmission process, it also leads to the increase of the energy consumption for storing the data. [2] indicated that the data replication strategy should depend on the popularity of the data. Figure 7 shows the contribution of storage, servers and transmission to the

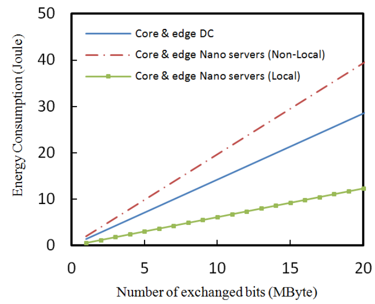

Fig. 6. Energy consumption of core and edge networks for accesing data from different locations [11]

total power consumption of IPTV services, where 20 replicas of a 2-hour SD movie are stored in 20 different data centers [2]. We can see that the storage cost dominates the total energy consumption when the movie is rarely downloaded, and the transmission cost becomes significant as the data popularity increases. Regarding this, for movies that are frequently downloaded, it is more energy-efficient to keep a relatively large number of replicas to reduce the energy consumption in the transmission process; and for movies that are rarely downloaded, it is more energy-efficient to keep a relatively small number of replicas to reduce the energy consumption in the storage.

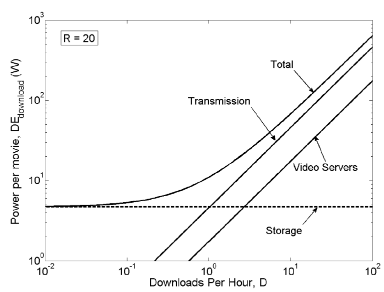

Fig. 7. The contribution of storage, servers and transmission to the total power consumption of IPTV services with respect to data popularity [2]

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[10] compared the energy consumption for downloading movies from nano data centers and from centralized data centers with respect to the access frequency, under the scenario that a centralized data centers keeps two replicas of each data, and nano data centers keeps 2, or 10, or 100 replicas of each data. The result indicated that a centralized data center is more efficient than nano data centers for unpopular data.

Thus, we regard finding the balance between the transmission distance and the number of replicas as one the technical challenges towards the development of nano data centers. From our view, a possible solution is to detect the popularity of each individual data dynamically, and adjusting the number of replicas for each data accordingly. However, further study on the negotiation and configuration mechanism is required.

4 EVALUATION/RESULTS

We collected all challenges that we figured out in the section 3 and put them into three categories: political, legal and technical issues. Table 1 summarizes all challenges that we have found in our research.

Political issues	Legal issues	Technical issues
Distribution of data between ISP: including international partnerships with political policies	Creating a legal basis for data distribution that takes into account the needs and requirements of different countries, including cross-border issues.	Activation time: maximize the active time of nano serves, and avoid a large idle time, to get a hight ratio
Net neutrality: conflict of interest, if ISP would also provide data	Data Protection of the EU (GDPR)	Access network: futher study on the access network that the end-user use, also on the selection of the access network, depending on the access rate
	Liability of stored data in the nano server	Trade-off: Distance: finding balance between the transmission distance
		Trade-off: Replication: finding a well-chosen number of data replicas

Table 1. Summary of all challenges towards a nano data center platfrom, categorized by political, legal and technical issues

It can be seen that there are more technical challenges on the one hand, and a few challenges in political and legal categories on the other. Nevertheless, these non-technical challenges must not be underestimated, because only a rough estimation is possible in this field. Furthermore, as we have above-mentioned, these issues will give just an overview. For more detailed analyses, further studies are required.

5 DISCUSSION

In our paper we analyze the multiple challenges towards the development of nano data centers. There are a few papers about that approach as a green alternative or addition to monolithic data centers. These works include the technical and non-technical issues towards these nano servers. But nowadays, nano data center platforms are not yet in practical use. In our research we figure out the challenges towards the implementation of such a platform.

6 CONCLUSION AND FUTURE WORK

In section 3 it can be seen that the implementation of a nano data platform not as easy as assumed in [13] or other works. There are a few more steps that have to be taken before this can be put into practice. Some issues still have to be investigated and researched in more detail. In our work we figured out the main challenges for the next steps towards a common use of nano date servers. For next steps more studies are required regarding technical and non-technical challenges. This work can not be seen as exhaustive, therefore, there might be more challenges than we have considered, especially such of political and legal origin. This is also closely related to the geographic location and the local jurisdiction.

In 3.3.1 we have defined the technical challenges. These also partly require further investigations. On the one hand, this means further investigations into a well-chosen activity time of the nano server in order to achieve better energy efficiency. Further detailed research is on the other hand also needed for the selection of access networks to investigate which network is most suitable. Finally, another investigation is needed to find a good balance between the transmission distance and the number of data replicas.

REFERENCES

[1] Automattic. 2005. WordPress.com. (2005). http://wordpress.com (Accessed on 13/01/2018).

[2] Jayant Baliga, Robert Ayre, Kerry Hinton, and Rodney S. Tucker. 2011. Architectures for Energy-Efficient IPTV Networks. *IEEE Systems Journal.* 5 (09 2011), 518–527. https://doi.org/10.1109/JSYST.2011.2165601

[3] Jayant Baliga, Robert Ayre, Wayne V. Sorin, Kerry Hinton, and Rodney S. Tucker. 2008. Energy Consumption in Access Networks. IEEE. https://doi.org/10.1109/OFC.2008.4528538

[4] Yahel Ben-David, Shaddi Hasan, and Paul Pearce. 2011. Location Matters: Limitations of Global-Scale Datacenters. (2011).

[5] Meeyoung Cha, Pablo Rodriguez, Jon Crowcroft, Sue Moon, and Xavier Amatriain. 2008. Watching television over an IP network. ACM, 71–48. https://doi.org/10.1145/1452520.1452529

[6] Inc. Cisco Systems. 2017. The Zettabyte Era: Trends and Analysis - Cisco. (07 2017). https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html#_Toc484556821 (Accessed on 11/05/2017).

[7] Council of European Union. 2016. Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation). (2016). Chapter 3, Articles 12-23.

[8] Council of European Union. 2016. Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation). (2016). Chapter 5, Articles 44-50.

[9] S. Eum, Y. Shoji, M. Murata, and N. Nishinaga. 2015. Design and Implementation of ICN-enabled IEEE 802.11 Access Points As Nano Data Centers. *J. Netw. Comput. Appl.* 50, C (April 2015), 159–167. https://doi.org/10.1016/j.jnca.2014.07.031

[10] Anja Feldmann, Andreas Gladisch, Mario Kind, Christoph Lange, Georgios Smaragdakis, and Fritz-Joachim Westphal. 2010. Energy Trade-offs among Content Delivery Architectures. IEEE. https://doi.org/10.1109/CTTE.2010.5557700

[11] Fatemeh Jalali, Robert Ayre, Arun Vishwanath, Kerry Hinton, Tansu Alpcan, and Rodney S. Tucker. 2014. Energy Consumption of Content Distribution from Nano Data Centers versus Centralized Data Centers. *SIGMETRICS Performance Evaluation Review* 42 (2014), 49–54.

[12] Leibniz-Rechenzentrum. 2014. Green IT at Leibniz Supercomputing Centre. (02 2014). https://www.lrz.de/wir/green-it_en/ (Accessed on 11/19/2017).

[13] P. Rodriguez N. Laoutaris and L. Massoulie. 2008. ECHOS: Edge Capacity Hosting Overlays of Nano Data Centers. *SIGCOMM Comput. Commun. Rev.* 38 (01 2008), 51–54. https://doi.org/10.1145/1341431.1341442

[14] Otto Palandt and Peter Bassenge. 2018. *Bürgerliches Gesetzbuch - mit Einführungsgesetz (Auszug), Allgemeines Gleichbehandlungsgesetz (Auszug), BGB-Informationspflichten-Verordnung, Unterlassungsklagengesetz, Produkthaftungsgesetz, Erbbaurechtsverordnung, Wohnungseigentumsgesetz, Hausratsverordnung, Vormünder- und Betreuervergütungsgesetz, Lebenspartnerschaftsgesetz, Gewaltschutzgesetz (Auszug).* Beck. §1004.

[15] Prof. Dr. Dieter Kranzlmüller. 2017. Recorded interview. (12 2017). Recording of the interview available (in German). Contact Andreas Scholz for further details.

[16] Technicolor. 2011. Technicolor Research & Innovation - Nano Data Center. Online video. (01 2011). https://www.youtube.com/watch?v=uvkBUKqFbkI

[17] Vytautas Valancius, Nikolaos Laoutaris, Laurent Massoulié, Christophe Diot, and Pablo Rodriguez. 2009. Greening the internet with nano data centers. In *CoNEXT*. ACM, 37–48.

A QUESTIONNAIRE

(1) On the website of the LRZ it can be read that *Green IT* is important [12]. What has been achieved or improved so far?

(2) In 2012, the LRZ was awarded the German Data Center Award for *energy and resource efficient data centers* [12]. What makes the LRZ better on *Green IT* than other data centers?

(3) What does the LRZ offer its customers? Are there any special *Green IT* services available? Does the customer have an influence on more environmentally conscious use?
(4) Today's use of Internet services has changed massively [6]. How has the LRZ adapted accordingly?
(5) Why are the big data centers still so popular? What are the reasons/advantages? Are these political, economic or technical?
(6) Are there any disadvantages with monolithic data centers?
(7) Have you heard of an alternative solution to monolithic data centers? There are, among others, some research on nano data centers. Does the LRZ also work with these approaches? What is your opinion?
(8) In your opinion, what are the advantages and disadvantages of nano data centers?
(9) How does the LRZ see the data centers of the future? What could be possible? Is it realistic that monolithic data centers could be replaced by special peer-to-peer networks?
(10) Do you think there are any difficulties or special challenges that need to be solved in order to implement nano data centers suitable for the mass or as new state of the art? What are the difficulties oder challenges in your opinion?
(11) Do you have any idea or approach how to solve these difficulties or challenges?
(12) Would you have an idea for other alternative systems?