The impact of the Internet of Things on the demand of cloud resources

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ABSTRACT,
This research gives insight into the impact of the Internet of Things on the demand of cloud resources and explores the key challenges for the future. This subject was investigated by presenting a System Dynamics forecasting model to predict cloud storage and traffic demand over the next ten years. This demand arises because of the enormous data generation of IoT devices such as: smart homes, medical sensors, fitness trackers and smart security systems. Simulations of the model predict that storage demand is expected to grow with a CAGR of 33.6% and traffic demand with a CAGR of 37.8% in the period from 2018 to 2032. When the rise of 5G is included, the storage demand increases even more. However, the traffic CAGR will decrease due to the shift of computing and storage closer to the endpoint through the use of fog and edge computing. This trend will continue due to the enormous growth of generated data. A cloud-only model is not sustainable for the future because certain computation and storage needs to be brought closer to the endpoints in the form of edge and fog computing. Combining these technologies by having a solid IoT infrastructure is crucial for companies to take advantage of the benefits that IoT provides.

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Internet of things, Cloud computing, Fog computing, Edge computing, System Dynamics

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1. INTRODUCTION

Since the emergence of the Internet of Things (IoT), the applications and use of this technology has increased significantly. The IoT consists of physical devices that generate data, communicate and share information, all interconnected over the internet (Patel et al., 2016). It is estimated that approximately 10 billion devices were connected to the internet in 2021 and according to a forecast from Gartner (2021) this number is expected to rise to 27 billion in the year 2025. "The IoT paradigm is aimed at formulating a complex information system with the combination of sensor data acquisition, efficient data exchange through networking, machine learning, artificial intelligence, big data, and clouds"(Rahman et al., 2019).

This expected growth is partly due to the further evolution of industry 4.0. The internet of things is one of the driving forces behind industry 4.0 together with artificial intelligence and machine learning (Dong-Hyun et al., 2017). In recent years, industry 4.0 has had a major impact on manufacturing and supply chains. It has influenced the production environment with an introduction of information and communication systems which has led to a strong growing degree in automation possibilities.(Javaid et al., 2022). The applications of the industrial IoT are promising in the field of monitoring factory processes and making automatic data-driven decisions.(Javaid et al., 2021) In addition to industrial applications, IoT can be used in many different ways. IoT can also be used by consumers in the form of smart homes applications or wearables such as smartwatches, virtual glasses, health monitoring and home security. The IoT market is still developing rapidly and more applications that are now being researched could be used in the future.

To connect smart devices and enterprises, there are several options for storing and processing data. IoT applications produce huge amounts of data in short time frames and often these devices are not equipped with a lot of storage space or computation power. A commonly used solution for this is the use of cloud computing, which makes it easier to perform complex computations in a scalable environment(Tanweer, 2021). The main difference between cloud computing compared to traditional computing is that cloud computing runs on servers facilitated by external hosting parties such as: Microsoft Azure, Amazon Web Services and Google Cloud and traditional computing takes place locally on servers. (Suruchee et al., 2014). Cloud computing offers many advantages such as: cost savings, it provides direct access to hardware resources without upfront investments, scalability and enabling services that would not be possible without cloud (Avram, 2013).

When computing and data storage is shifted from remote cloud to a system closer to the data source it is called edge or fog computing. In edge computing, the processing and storage happens on devices (also known as endpoints). Devices that use edge computing have device-to-device connectivity and are connected to the fog layer.(Hong et al., 2018) Fog computing takes place at the edge of the network and can consist of various things such as routers and switches where storage and computation take place (Nitinder et al., 2017) "Fog computing bridges the gap between the cloud and end devices (e.g., IoT nodes) by enabling computing, storage, networking, and data management on network nodes within the close vicinity of IoT devices"(Yousefpour et al., 2019).

Advantages of edge and fog computing over cloud computing are: improved speeds, supports real-time interaction and improved security. When it comes to large amounts of data and cheaper computing resources, cloud has more advantages. Fog and edge computing are not a replacement for cloud computing, but the technologies are complementary to each other and a good mixed infrastructure ensures optimal computing results(Francis et al., 2017).

To give an idea of the architecture of IoT, figure 1 gives an overview of four different layers. In literature, different types of models and frameworks are used to outline the IoT architecture. They are all described with different layers but the amounts and naming of layers differs per author. In this paper we follow the 4-layer architecture of Saba et al. (2021). The different layers are: the Perception layer, the Network layer, the Processing Layer and the Application layer. The Perception layer is the physical layer in the IoT architecture that has several sensors connected to the internet that generate sensory data. Examples of this could be industrial robots, cameras or Radio Frequency Identification devices. The main task of the perception layer is to generate data with which can be used by the application layer. The devices on the perception layer are also referred to as endpoints and the perception layer can also be called the edge layer. The network layer takes care of passing data from the perception layer to the application layer. This communication with other layers takes place at a short distance via technologies such as Bluetooth and ZigBee and to a nearby gateway. Other technologies such as 2G, 3G, 4G, 5G and Power line Communication are used for communication over a greater distance. Computing and storage at this layer is called fog computing and the layer can be also referred to as the fog layer. The processing layer consists of databases and servers where large volumes of data generated by the perception layer are stored and used to perform various tasks such as big data analysis. This layer can also be called the core, which consists of datacenters including private and public cloud(Reinsel et al., 2018). The top layer of the IoT architecture is the application layer, also known as the business layer. The application layer ensures that the specifications for the end user are met and that the analyzed data in the processing layer is presented in a clear way.

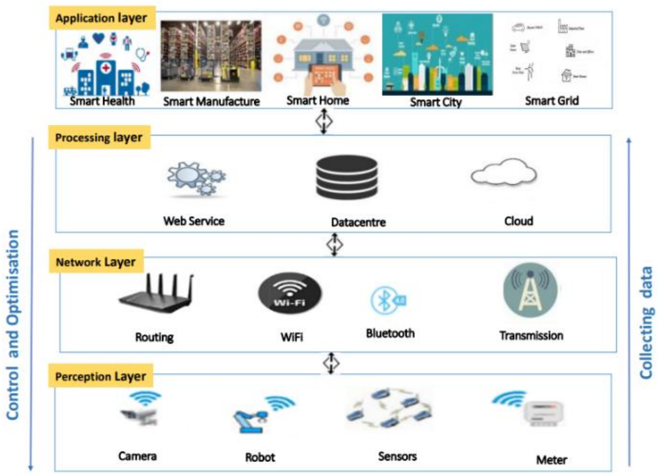

Figure 1. IoT infrastructure Saba et al. (2021)

A development impacting IoT and cloud computing is the rise of 5G. This is a new telecommunications standard that will follow its predecessor (4G). 5G ensures lower prices, lower battery consumption and lower latency than its predecessor. This is mainly because 5g uses Ultra-Wide Band (UWB) with higher bandwidths and lower energy levels.(Mohsen, 2020) "The 5G enabled IoT (5G-IoT) will connect massive number of

IoT devices and make contributions to meet market demand for wireless services to stimulate new economic and social development."(Shancang et al., 2018)

The main goal of this research is to gain insight into the role of IoT on the demand of computational resources and storage needs. This leads to the following research question:

What is the impact of the Internet of Things on the demand of cloud resources?

To answer this question, there are two sub-questions:

How will the Internet of Things trend grow over the next 10 years?

What will be the key challenges for the future of the Internet of Things in relation to cloud computing?

This research will be conducted by creating a forecasting model. This will allow predictions to be made about the future of IoT in relation to cloud computing.

2. LITERATURE REVIEW

In the literature review available research is presented on IoT in the context of cloud and various forecasts on the IoT market via a systematic literature search in Scopus and Google Scholar.

Shadi et al. (2020)made a forecast of the IoT market for the period from 2020 to 2030. A prediction is made about the amount of connected IoT devices and the market value expressed in dollars. The forecast predicts total spending of more than 1 trillion dollars in the year 2023, as well as approximately 100 billion connected devices. In addition, an annual growth rate of 20% is expected in the period 2020-2030. This paper mainly shows the potential of the IoT market and devotes this enormous growth mainly to the integration between Artificial Intelligence (AI), Big-data and IoT technologies.

Gartner (2021) has made a forecast of IT Services for IoT in the period 2019-2025. They estimate that 11.7 billion devices were connected to the internet in 2020 and this number is expected to grow to 25 billion by the end of 2021. The IoT market value is estimated at more than 58 billion dollars in 2025, which represents a growth rate of 35 billion. % from 2020. The growth is mainly attributed to the broad application of IoT solutions, both as sector-specific technology and more widely applicable applications.

Statista (2022) provides a forecast of IoT devices connected worldwide for the period 2019-2030. The estimate of the number of devices is 8.7 billion in 2020, which is expected to rise to more than 25 billion in 2030. They estimate that about 60 percent of these devices are used (which is largely due to the share of mobile phones) in the consumer market the other 40 percent in the industry. This ratio is expected to remain the same for the next 10 years.

Cisco (2020) provides comprehensive forecast/analysis on digital transformation across various business segments. Machine to machine applications are predicted to have a CAGR of 19% from 2018 to 2023. For mobile IoT applications, even a CAGR of 30% is expected over the same period. In addition, Cisco also reviews technologies that influence the development of IoT and cloud computing. Broadband speed (measured in Mbps) is a crucial enabler of IP traffic and is expected to more than double from 2019 to 2023. The importance of Wi-Fi is also underlined in the growth of IoT because connectivity is largely via Wi-Fi and edge solutions are also becoming increasingly popular.

IoT Analytics (2022)compares general market predictions made over: the total annual number of connected devices, annual revenue of the IoT market and the annual economic value of the IoT market. Although different forecast models differ in outcome, they all agree that the IoT market will see strong growth in the coming years, the annual growth rates ranging from 14% to 29%. The segmentation of the IoT landscape is also examined, which shows that the potential of business applications is greater than the consumer segment. The segment with the greatest potential is the application in manufacturing, which could potentially account for a quarter of the total IoT market.

The International Data Corporation (IDC) (2021) has made a prediction of the total global volume of data generated by IoT devices , this number would increase to 79.4 zettabytes (ZB) by 2025. The CAGR from 2018 to 2025 is estimated at 28.7%. The main reason for this growth will be the proliferation of IoT devices in the industrial and automotive sector. In addition, a strong growth in the adoption of IoT technology in households (e.g. smart homes and wearables) is also expected in the near future.

Grand View Research (2021)has made a forecast about the Industrial Internet Of Things Market Size with various trends analysis. There is a strong increase in the application of IoT in the industrial field. A CAGR of 22.8% in the general IIoT market is expected in the period from 2021 to 2028. A distinction is made between different segments within the IIoT of which the manufacturing segment is expected to have the largest market share. This is due to the growing need for centralized monitoring and predictive maintenance on assets.

Keshav et al. (2022) made a forecast about the development of the smart cities market. The global smart cities market is projected to reach a value of $6,061.00 billion by 2030, generating a CAGR of 25.2% over the period from 2021 to 2030. The growth is mainly driven by government initiatives to improve urban environments. to make better use of natural resources, public safety and security also play an important role in the growth of this market.

(Vakilian et al., 2022)provides research on optimizing cooperation between fog nodes. Due to the significant volumes of data generated in the IoT, cloud infrastructure alone cannot process all of this data. To solve this, fog computing has been proposed as a supplement to the cloud. One of the main issues in fog computing is deciding how much of the workload should be offloaded to the cloud and this research presents a solution to this problem in the form of an algorithm to enhance cooperation between fog nodes.

Ahmed et al (2019) presents research on the trust and reputation of the Internet of Things. Due to the high growth rate of IoT, traditional security approaches fail to provide adequate security mechanisms for the current infrastructure. This research describes the emergence of trust and reputation (TR) in IoT, to monitor behavioural deviation of IoT entities.

3. METHODOLOGY

The goal of this research is to develop a forecasting model to predict the demand of cloud resources generated from data of IoT devices. For the definition of 'cloud resources demand' a two-part distinction is made between data storage and network traffic. With this forecast model a prediction is made how the IoT market will develop over the next 10 years with a focus on where the data is generated and where it is stored.

3.1 System Dynamics Terminology

To make this forecast model, a System Dynamic modelling technique is used. System dynamics is a modeling approach that can describe nonlinear behavior of complex systems over time. This modeling approach is used to predict and understand changes over time in complex environments and it was initially applied to model high complex environments like industrial/economic systems and population trends.(Olson, 2003) There are several tools in which System Dynamics models can be built, but in this research Insight Maker is used. "This is a free, open-source modeling and simulation tool developed using web-based technologies and supports graphical model construction using multiple paradigms."(Fortmann-Roe, 2014) Insight Maker uses several building blocks that are referred to as 'primitives'. The key primitives are: stocks, flows, variables and converters. Stocks are used to store values and are visually represented as squares. To move values between stocks Flows are used, which are represented with a blue arrow. Variables represent the rates of change of the stocks and are presented as ovals. Converters can be used to perform non-parametric transformation functions and provide the ability to load tabular data and are displayed as a green hexagon. Links can be used to connect these primitives. These links can transfer information from one primitive to another, visually links are represented as a dotted line with an arrow.(Fortmann-Roe, 2014)

3.2 Conceptual framework

The conceptual framework for IoT traffic and storage demand can be seen in figure 2. This model starts with the generation of application workload by different segments formulated by Gartner (2021): Utilities, Government, Building Automation, Physical Security, Manufacturing & Natural Resources, Automotive, Healthcare Providers , Retail & Wholesale Trade, Information and Transportation. The unit of application workload is workloads, expressed in millions.

The same architecture is used for the distribution of workload as described in the introduction. It is assumed that there are three places where data can be stored and processed: core, fog or edge. Core is everything from the processing layer, this contains all enterprise and cloud data centers. The fog layer consists of servers and appliances that are not in core data centers. Examples include: routers, access points and gateways. Edge refers to the devices at the edge of the network, such as: sensors, cameras and other IoT devices. These different layers are closely linked and data is transferred between the different layers. Quite a lot of research has already been done about resource allocation between the different layers, and which data is most suitable for each layer.

The application workload and the workload distribution together form the total workload and from this variable the demand for storage and traffic is determined.

As discussed earlier in the literature review, the predictions of forecast models about IoT vary widely. This is mainly because this is a relatively new technology and there are many external factors influencing IoT growth that are still uncertain. Many new technologies follow a similar pattern of progress, but the speed of this differs enormously and some technologies quickly become redundant when new innovations arise.

The System Dynamic Model is based on data from other forecasting models and general research into IoT and cloud/edge computing. The exact data with references can be found in the next chapter.

4. DESIGN OF THE IOT SYSTEM DYNAMIC MODEL

For the development of the System Dynamics Model we follow the conceptual framework as presented in last chapter. The model consists of three different components: application behavior, workload distribution and conversion to storage and traffic demand. The different stocks in the model consist of an increase and a decrease flow linked to a CAGR variable. CAGR stands for Compound Annual Growth Rate and is the annual average rate of growth between two different years, given by the formula:

$$CAGR(t_0, t_n) = \left(\frac{V(t_n)}{V(t_0)}\right)^{\frac{1}{t_n - t_0}} - 1$$

Where t_n stands for the ending value, t_0 for the start value and n for the amount of years. The increase and decrease flows

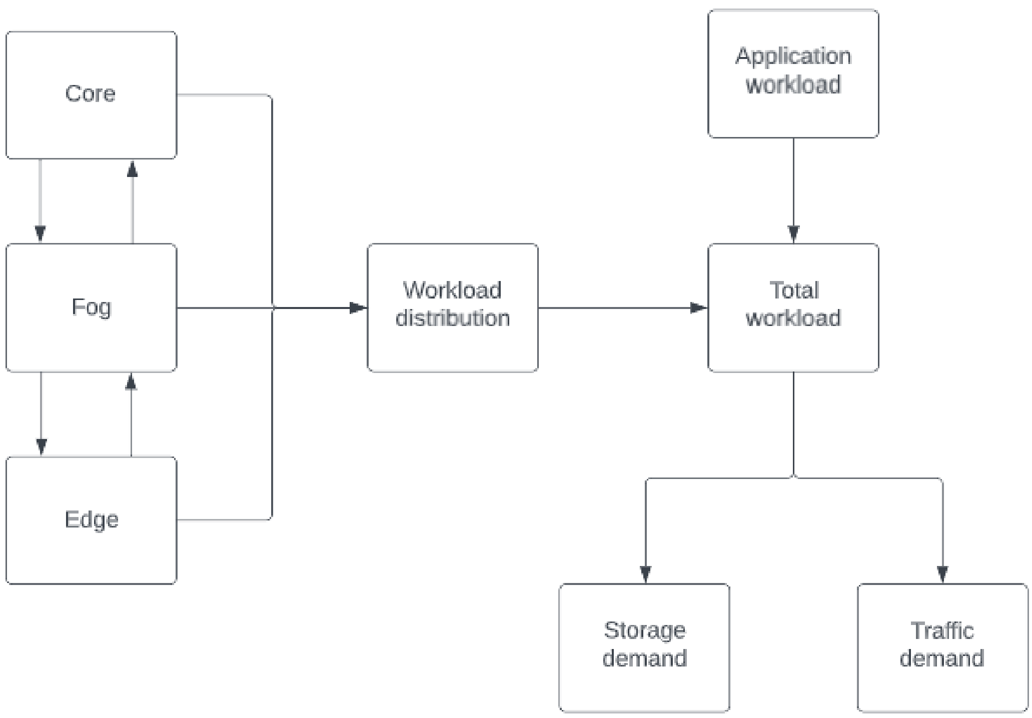

Figure 2. Conceptual Framework

consist of IF-Statements to check whether the CAGR value is positive or negative and then multiply this by the stock.

An overview of the model can be seen in figure 3. and the link to open this model in Insight Maker will be at the bottom of this paper (Appendix).

4.1 Application workload

To determine the distribution of the workloads over the different IoT segments, we use data from (Gartner, 2021). As discussed earlier in the methodology, a distinction is made in 8 IoT segments: Utilities, Government, Building Automation, Physical Security, Manufacturing & Natural Resources, Automotive, Healthcare Providers, Retail & Wholesale Trade, Information and Transportation. The data (Table 1) represents the global installed base in billions of units per segment and for the period between 2018 and 2020 a CAGR er segment is calculated. The different IoT segments can be found in the model under the application workload section. These variables each have a CAGR which are connected with increase and decrease flows.

Every year the new distribution is re-calculated by adding the values of all segments together and dividing this by the new values of each segment. This way you get a new distribution every year, taking into account the growth rate of each separate segment. This information is stored in a vector in the variable: application endpoint distribution.

For the total amount of workloads produced by IoT devices, the data from the report from Cisco (2018)is used. This report describes different categories of which Database, analytics and IoT is one. This data can be seen in table 2. Since the data from Gartner (2021) starts at 2018 we will run the simulation from 2018 so we use 51 million as base value for the application workload.

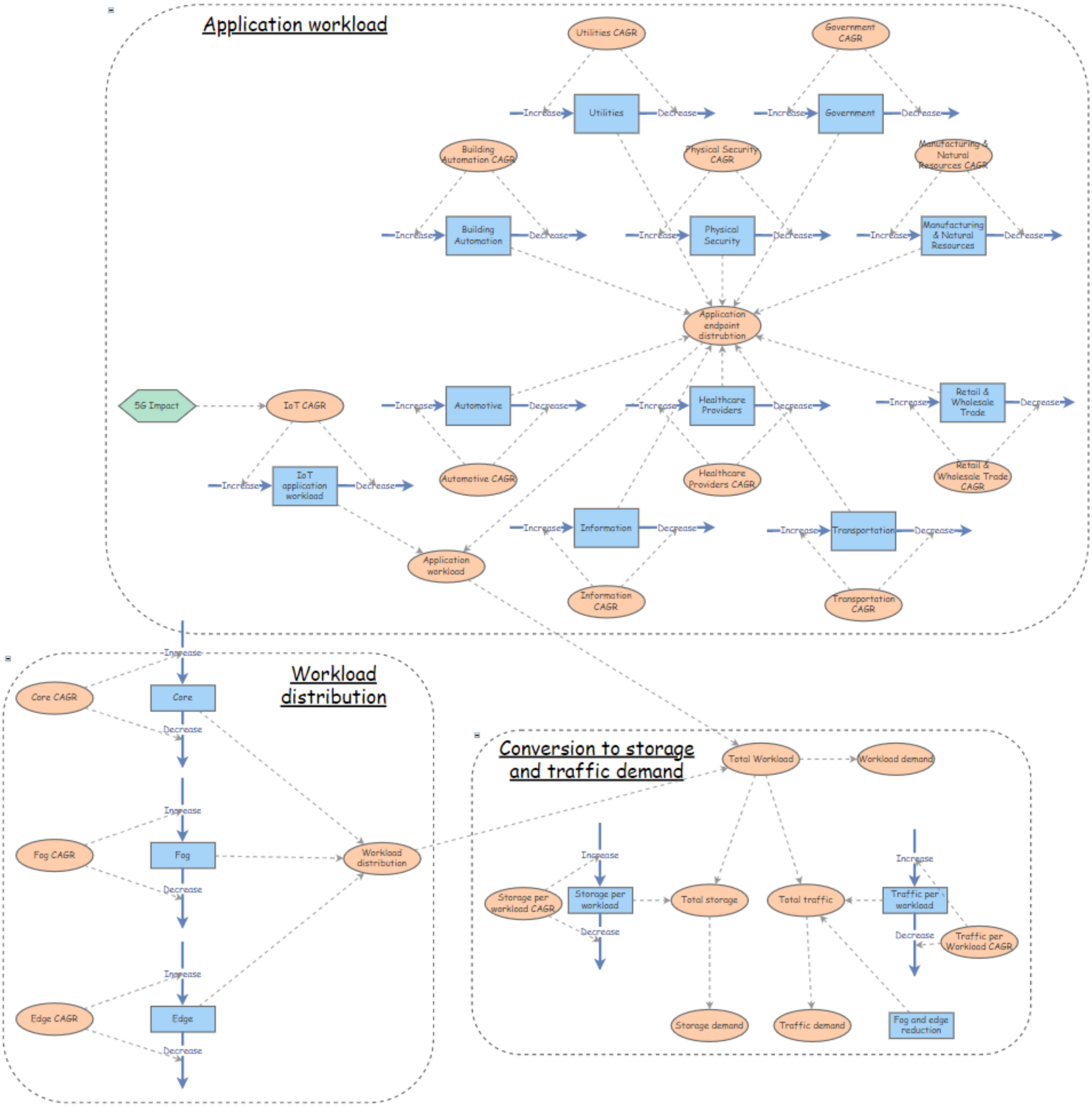

Figure 3. System Dynamics model

Segment	2018	2019	2020	CAGR
Utilities	0,98	1,17	1,37	0,12
Government	0,4	0,53	0,7	0,21
Building Automation	0,23	0,31	0,44	0,24
Physical Security	0,83	0,95	1,09	0,10
Manufacturing & Natural Resources	0,33	0,4	0,49	0,14
Automotive	0,27	0,36	0,47	0,20
Healthcare Providers	0,21	0,28	0,36	0,20
Retail & Wholesale Trade	0,29	0,36	0,44	0,15
Information	0,37	0,37	0,37	0,00
Transportation	0,06	0,07	0,08	0,10

Table 1. Application workload (Gartner, 2021)

4.2 Workload distribution

To determine how the workloads are distributed over the core, fog and edge, we use data from (Reinsel et al., 2018). In this research a distinction is made between data storage and data creation. In this case, the forecast workload distribution of data storage is used. As can be seen in the conceptual framework, the different layers work closely together but are treated as separate entities in the model. However, this does not mean that the different layers do not work together and exchange data.

The data shows (Table 2) that there is an increasing shift towards the core compared to edge and fog, although edge and fog computing are suitable solutions for IoT. It is therefore good to mention that these data represent the distributions of all data and not just specifically of IoT data, this is something that will be explained in more detail later in the scenarios section.

This data is added to the model in the workload distribution section. The stocks: core, fog and edge are each linked to a CAGR variable that can also be found in table 2. The changes in the distribution of the workloads over time are adjusted with the same principle as the application workloads. By adding up the values of the stocks every year and dividing the newly generated value of each stock by the sum, a new workload distribution is created every year. These values are stored in a vector in the workload distribution variable.

In the model it is assumed that the workload distribution has no relationship with the different application workload segments and therefore each segment follows the general distribution.

4.3 Conversion to storage and traffic demand

The applications workloads with its different segments and the workload distribution over core, fog and edge is stored in the variable: total workload, and the sum of these can be found in the variable workload demand. To connect this and to calculate the demand in storage and traffic, data from (Cisco, 2018) was used.

In table 3 is an overview of application workload, application storage, application network, application storage workload and application network per workload of the aforementioned category Database, analytics and IoT.

Total storage is calculated by multiplying storage per workload with the total workload and by taking the sum of this storage demand is calculated (Koot et al., 2021). The same principle works for traffic demand with traffic per workload.

However, with traffic we a distinction is made between cloud, fog and edge. Research by Blesson et al. (2020) shows that data traffic transferred using a fog model reduces traffic by 90% compared to a cloud model. To process this in the model, a separate stock has been created that, with a vector in it, reduces the values of traffic demand from edge and fog by 90%.

5. SIMULATIONS

5.1 Simulation settings

To simulate the demand of cloud resources (storage and traffic), a time span of 10 years is used. This time frame was chosen because technologies have time to show their effect and thus reflect the change in the IoT market. The simulation will start from 2018 as the data from Gartner (2021)is the limiting factor for more historical data, the rest of the available data originates from 2016. From the historical data a CAGR has been calculated for the different variables that show the growth of the different components. One-year steps are taken in the simulation because the available data is on an annual basis and

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	CAGR
Edge	0,64	0,59	0,52	0,45	0,4	0,37	0,33	0,3	0,28	0,27	-8%
Fog	0,03	0,04	0,05	0,06	0,08	0,08	0,09	0,09	0,09	0,09	12%
Core	0,33	0,37	0,43	0,49	0,52	0,55	0,58	0,61	0,63	0,64	7%

Table 2. Workload distribution (Reinsel et al., 2018)

	2016	2017	2018	2019	2020	2021	CAGR
Application workload (Millions)	33	41	51	61	72	87	21,4%
Application storage (EB)	128	168	219	280	370	487	30,6%
Application network (EB)	416	532	652	781	938	1140	22,3%
Application storage (EB/workload)	3,88	4,10	4,29	4,59	5,14	5,60	7,6%
Application network (EB/workload)	12,60	12,97	12,79	12,80	13,03	13,10	0,8%

Table 3. Application storage and network (Cisco, 2018)

the forecast is mainly intended for long-term effects of the described technologies and developments.

5.2 Base model

The forecast for storage and traffic demand are simulated for the period 2018-2032, assuming that the current trends as reflected in the input data will continue.

5.2.1 Application workloads

The total application workload will increase from 2018 with a starting value of 51 million workloads to a value of 770 million workloads in 2032. This growth is caused by the rapidly increasing connected devices to the internet and the general growth of the market.

The building Automation segment is experiencing the greatest growth, mainly due to the emergence of Smart Homes and Smart cities. Another segment that is in line with this is the rise of smart cars, which ensure strong growth of the IoT automotive industry. Cars are increasingly equipped with sensors that enable autonomous driving and make driving more efficient. The segment with the largest share of workloads in 2032 is the Government. Governments all over the world intend to increase the effectiveness of public services by applying IoT (KUMAR, 2019) .The utilities segment also has a large market share through the use of various IoT applications that help more efficiently distribute and use water, gas and electricity that will be needed to meet this demand in the future.

5.2.2 Workload distribution

A development that has been underway for a number of years is the shift from traditional data center workloads to cloud and hyperscale data centers. This trend will continue in the future and will result in that 95% of all data center workload will take place in the cloud.

The shift to cloud will result in the core's share in the distribution of workloads growing. Where 43% percent of data storage in the core still takes place in 2018, this will increase to 75% in 2032. The share of the fog layer will also increase due to the possibilities of fog computing, this value started at 5% and will increase to 16 % in 2032.

5.2.3 Storage and Traffic demand

The increase in data storage demand for the core, fog and edge has increased from 94.1, 10.9 and 113.7 EB in 2018 to a value of 9176, 2148 and 1358 EB in 2032. This results in a total of 12682 EB in 2032 and a CAGR of 33.6% over the forecast period 2016 to 2032 has been calculated. This is mainly due to the sharp increase in data generated by IoT devices along with

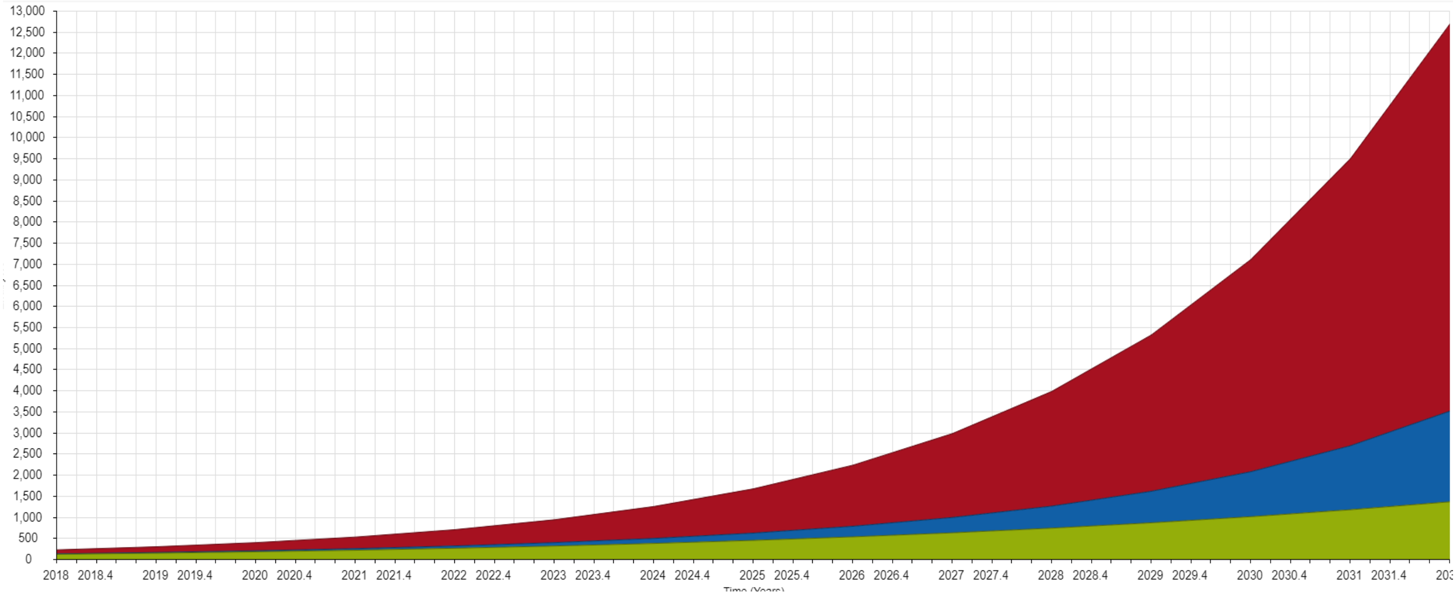

Figure 4. Storage demand base scenario

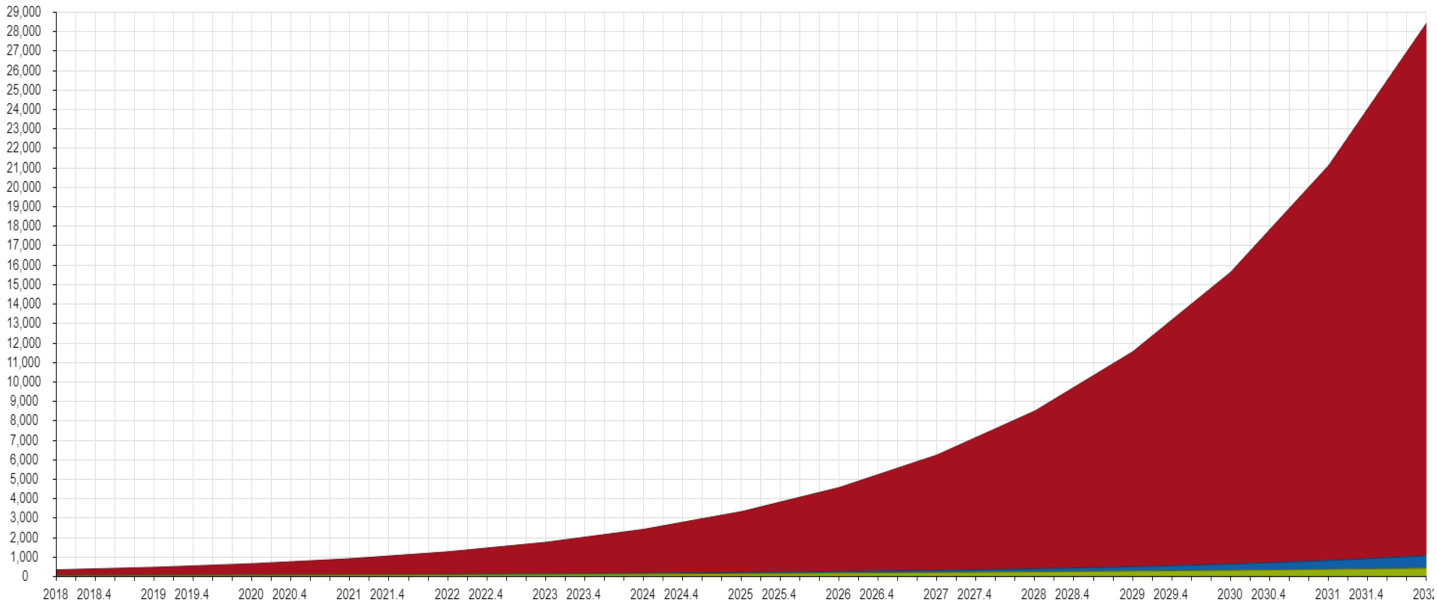

Figure 5. Traffic demand base scenario

the demand for analytics and other forms of data usage.

The increase in traffic demand for core, fog and edge increased from 280.4, 3.3 and 33.9 EB in 2018 to 27357, 640, 405 EB in 2032 with a CAGR of 37.8%. The main traffic will consist of traffic to the core, from the core and between the core. Edge and fog computing reduce the total amount of traffic because the data is closer to the source and therefore the share of the total traffic is also smaller.

5.3 Scenarios

The main advantage of using a System Dynamic model for forecasting is the creation and analysis of what-if scenarios. These scenarios are a speculation of what a particular situation might look like in the future. These scenarios provide an alternative to the base model and the outcomes will be discussed in the following sections. In this case, two different scenarios are considered:

- Emergence of 5G enables further IoT growth

- Shift to edge/fog computing

5.3.1 Emergence of 5G enables further IoT growth

From the results of the base model and the description of the literature, the demand for data storage and data traffic will increase in the coming years. Due to the huge data exchanges between IoT devices, the need for high capacity, high date rates and high connectivity has increased.(Alsulami et al., 2018) "The advent of 5G communications represents a potentially disruptive element in such a context. The increased data rate, reduced end-to-end latency, and improved coverage with respect to 4G hold the potential to cater for even the most demanding of IoT applications in terms of communication requirements."(Palattella et al., 2016)

Due to the expectation that 5g will further increase the growth of IoT demand, a converter has been added to the System Dynamic Model that has an impact factor on the CAGR of application workloads. This factor will not be applied directly but follows the development and growth of 5G described by a report from Ericsson (2022). The CAGR of the application workload will eventually reach 34.2%, which has been described as CAGR of the IoT Device Management Market by Grand View Research (2022). The starting value of the CAGR is 21.4% which is the same as in the base model, this value starts to increase from 2020 (due to the incipient emergence of 5G) and reaches its final value at 2027 because around this year 5G can be seen as a standard be across the globe.(Ericsson, 2022)

Simulating this scenario (figure 6 and 7)leads to strong growth in both storage and traffic demand. The total storage demand in this scenario increases to 34470 Exabytes in 2030 which gives a CAGR of 43.5% in this given period. The trend in the storage demand is striking. At first, quite the same pattern is followed as the base scenario, but due to the increase of the CAGR due to the emergence of 5G, the storage demand value increases enormously. The same principle applies to the growth of traffic demand. Although 5G greatly increases the demand for IoT, it has a higher efficiency than its predecessor 4G. For example, the traffic and network capacity is 100x larger and. This shows that these two developments go hand in hand and reinforce each other.

5.3.2 Shift to edge/fog

Another evolution in the world of computing is the rise of edge and fog. The predictions of the base model show that most storage and traffic can be found in the core. In this scenario, we look at the further application and growth of fog and edge computing and the impact this has on the cloud and IoT in general.

Many IoT solutions rely on the cloud for its storage and processing power capabilities. This is necessary for processing the large amounts of data generated by IoT devices. However, traditional cloud infrastructures cannot meet all requirements with this rapidly growing demand and therefore edge and fog computing are a good addition. Edge and fog computing probably won't replace cloud computing, but they complement each other and perform different tasks. An example of this is when you need a time-sensitive decision then it is useful to bring storage and computing closer to the source and use the fog or edge layer and for big data analysis on historical data computing and storage in cloud.(Cisco, 2015)

To simulate the impact of the shift to edge/fog, the workload distribution in the System Dynamic Model has been adjusted. This has been done by changing the base values of core, fog and edge. According to Gartner (2019) 91% of today's data is created and processed inside centralized data centers. The remaining 9% is equally distributed between the edge and fog and this is used as start values. The CAGR of each component

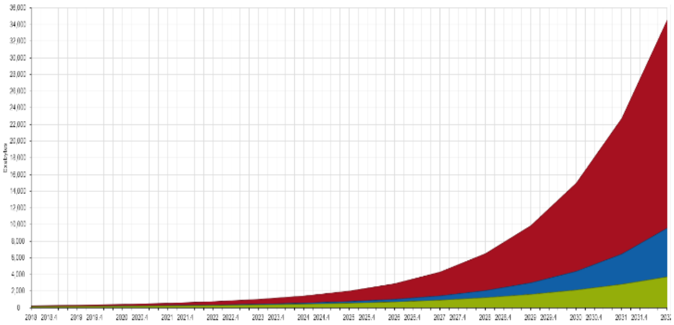

Figure 6. Storage demand forecast 5G scenario

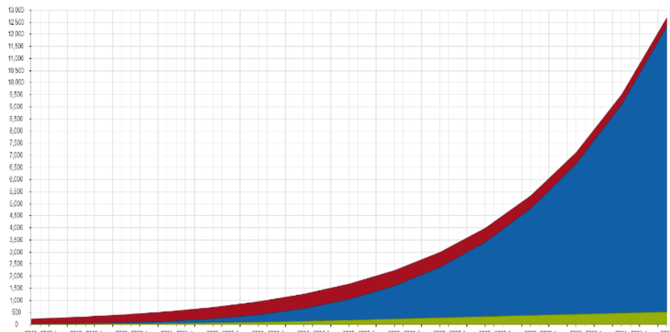

Figure 7. Traffic demand forecast 5G scenario

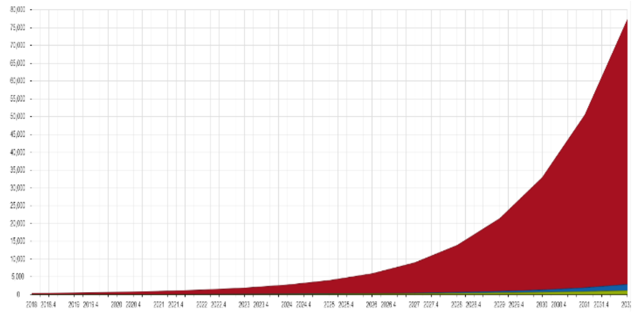

Figure 8. Storage demand forecast edge/fog scenario

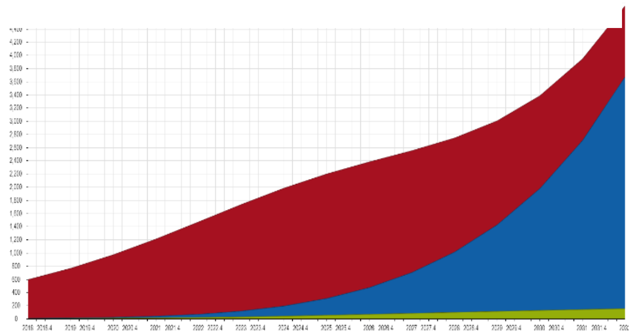

Figure 9. Traffic demand forecast edge/fog scenario

	Base model	5G Scenario	Edge/Fog Scenario	Combined scenario
Storage Demand 2018 (EB)	219	219	219	219
Storage Demand 2032 (EB)	12684	34471	12683	34471
Storage CAGR (%)	33,6%	43,5%	33,6%	43,5%
Traffic Demand 2018 (EB)	318	318	599	599
Traffic Demand 2032 (EB)	28403	77193	4866	13224
Traffic CAGR (%)	37,8%	48,0%	16,1%	24,7%

Table 4. Storage and Traffic demand of different scenarios

is based on research of the growth of the general markets of core/fog/edge from Grand View Research. The new CAGR of core is 15.7%, the new CAGR of fog becomes 61.3% and the CAGR of edge becomes 38.9%.(Grand View Research, 2022, 2022, 2022) With these new values we simulate the storage and traffic demand from 2018 to 2032.

Simulating this scenario (figure 8 and 9) results in the storage demand being dominated by the fog layer. Where fog in the base scenario still plays a small role, the storage demand increases to 11806 Exabytes in 2030, which is good for 93% of the total storage. While there will probably be a limiting factor that will not allow this growth to come this far, it does say something about the possibilities of fog computing. Something that stands out is the shape of the traffic graph over the years. This is because, as described earlier, the traffic from fog/edge is much less and the growth of fog starts later.

5.3.3 Combination scenarios

Where the 5G scenario increases the values of both storage and traffic, the storage demand for the edge/fog scenario remains the same and the traffic even decreases. This is because the edge/fog scenario brings storage and computation closer to the devices, resulting in less traffic. The two scenarios are strongly linked because 5G also increases the growth of edge/fog capabilities and the developments of edge/fog also have an impact on the growth of IoT.

To see this effect, a combined scenario of the growth through 5g and the shift to the edge/fog has also been simulated. This results in the same growth in storage demand as the 5G scenario from 219 EB in 2018 to 34471 EB in 2032, with a CAGR of 43.5%. The traffic demand is unique, since the total workload is increased by the rise of 5G, but at the same time there is also a shift to the fog/edge, resulting in a more efficient workload allocation and less traffic. Total traffic demand increases from 599 EB in 2018 to 13224 EB in 2032, with a CAGR of 24.7%.

A comparison between the different scenarios and the base model can be found in table 4. The storage demand and traffic demand of 2018 and 2030 are shown with their CAGR.

6. DISCUSSION

In the realization of this research and the System Dynamic Model several simplifications and assumptions have been made. In general, developments such as IoT are very complex and depend on many variables. The model itself is therefore already a simplification of reality and you can of course never be precise about the actual future. In addition, not much research has been done on this specific research subject (the link between IoT growth and cloud resource demand) and therefore public data is not always available for every modeling options.

6.1 Limitations and assumptions

An assumption made when establishing the model is about the workload distribution. Little specific data was available on how IoT workloads (and workloads in general) are distributed across the cloud, fog and edge. The data from Reinsel et al. (2018) has been used for this, but this data is about the entire datasphere instead of specific data about IoT. The issue with this is that IoT applications are very suitable for edge and fog solutions where other categories in the datasphere are not. This therefore gives a distorted picture of the distribution, but an attempt was made to include this in the research by making a specific scenario about the shift to the edge/fog.

The second assumption concerns the application workloads. The CAGR calculated from (Gartner, 2021) for the different segments is not based on actual workloads but on the installed base. The model therefore assumes that the devices from all different segments produce the same amount of workloads. In reality there will be differences, for example a smart healthcare machine will produce more workloads than a temperature sensor.

A third assumption that is made is the missing limiting factors to cloud resource demand and IoT growth. There could be factors that could hinder the growth of IoT, for example the end of Kryder's law and Nielsen's law. The first mentioned stands for the processor speed doubling every 18 months(Walter, 2005) and the second one that the users' bandwidth grows by 50% per year.(Nielsen, 1998) Another limiting factor could be the chip shortage. The demand for 20 million IoT chipsets will not be met in 2021 due to a shortage (Satyajit, 2021).

6.2 Theoretical implications

This research contributes to the literature by providing a new perspective on IoT forecasting by looking specifically at cloud resources. Most of the available literature on IoT forecasting consists of predictions about the total revenue of the market or the number of connected devices. This research establishes a link between application workload, the distribution between cloud, fog and edge and the total demand of storage and traffic.

While doing this research, a forecasting System Dynamic Model was created that can be used by future researchers to simulate new scenarios. Think of the impact of the growth of certain IoT segments or the addition of new data for the workload distribution to gain better insight into future cloud infrastructures. In addition, the forecasting model can be used as a basis for further expansion of new research. For example, the energy consumption of computing in the context of IoT or forecasting of IoT growth in geographical areas.

Furthermore, this research describes the different technologies and developments that influence the growth of IoT. The influence of 5G and the different computing possibilities on the development of storage and traffic demand are discussed .

6.3 Practical implications

This research shows that the IoT market will increase enormously in the coming years and that this growth will not be kept up with a cloud model alone. The need for storage and computing resources closer to the endpoints will become important for the successful implementation of IoT solutions in the future. Implementing IoT across different sectors means setting up a highly scalable IoT infrastructure with a combination of cloud and edge/fog solutions.(Onoriode et al., 2018)

This research also shows that there is a lot of data exchange between the different layers. These layers work closely together and by setting up good workload allocation methods, the IoT infrastructure and operation can be optimized. When data has extreme latency concerns, it is better stored and processed on the edge layer and when high amounts of data and processing power are required, it is better sent to the cloud.(Onoriode et al., 2018)

6.4 Future research

From this paper there are several possibilities for future research topics. This can differ from general research on the same type of subject or a specific follow-up research topics.

As mentioned in the limitations section, no research has yet been conducted into the precise workload distribution between cloud, fog and edge. By researching this, a better picture is created about the future IoT architecture and better demand predictions can be made for traffic and storage of IoT data.

Future research could also focus more on geographical differentiation within the demand for IoT resources. When this can be accurately forecasted, it can be responded to at a local level by realizing suitable IoT architecture. In addition, a better picture can be drawn about the demand for storage and traffic in different parts of the world.

7. CONCLUSION

The goal of this research was to gain insight into the role of IoT on the demand of cloud resources. To answer this, two sub-questions have been formulated: How will the Internet of Things trend grow over the next 10 years? and What will be the key challenges for the future of the Internet of Things in relation to cloud computing? Using the results of the System Dynamic model know it can be concluded that the demand for cloud resources produced by IoT devices is predicted to increase significantly. Storage demand is expected to grow with a CAGR of 33.6% and traffic demand with a CAGR of 37.8% in the period from 2018 to 2032. When the rise of 5G is included, the storage demand increases even more. However, the traffic CAGR will decrease due to the shift of computing and storage closer to the endpoint through the use of fog and edge computing. The key challenges for the future of IoT mainly have to do with cloud infrastructure. Due to the enormous growth of generated data, a cloud-only model is not sustainable for the future. Certain computation and storage needs to be brought closer to the endpoints in the form of edge and fog computing. Combining these technologies by having a good infrastructure is crucial for companies to make the most of the benefits that IoT provides.

The main research question (What is the impact of the Internet of Things on the demand of cloud resources?) has already been mostly answered by the sub-questions. Demand of storage and traffic will increase strongly and IoT computing and storage will shift to a mix between core, edge and fog where the impact of edge computing and fog computing will be significant.

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9. APPENDIX

The link to the System Dynamics model: https://insightmaker.com/insight/6OnHFZUCtjDP6PUEYPSRmq/Clone-of-Clone-of-Clone-of-Model-forecast

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