ECM2427: Literature Review on The Use of AI and Digital Twin in Networks and Intelligent Computing

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I. Introduction

With the emerging use of networks and advanced computing services, the use of digital twins will provide a strong backbone of improved reliability. A digital twin is a virtual model, hence twin, of any physical object, to allow for a real-time seamless maintenance and view of that object [1]. The digital twin being covered in this review is more specifically a network digital twin (NDT). A NDT allows for monitoring a physical network's data and allows for ensuring the network remains reliable. By augmenting a digital twin with artificial intelligence to monitor and operate the twin, it will make the twin far more efficient and effective. Using this will prevent crashes, outages, and improve network quality. The source selection methodology was based on finding relevant scholarly sources covering the use of digital twins or inherent issues with networks. The analysis methodology is to use these sources as a means for understanding how digital twins and associated technology works, to consequently analyze their structure.

II. Review

A. Challenges

1) Data Traffic: New technologies often pose challenges regarding to staying reliable. One of these issues is data traffic.

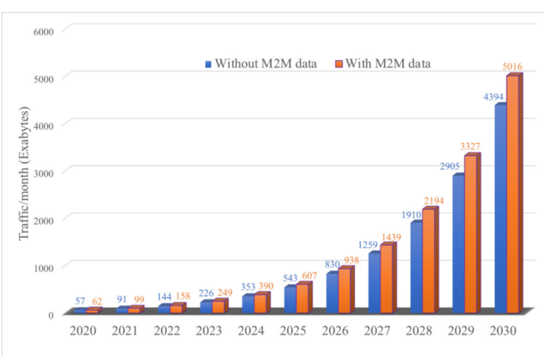

Fig. 1. Data Traffic Forecast [2]

From this projection, we can see a massive uptick in data traffic to be expected globally. More specifically, a 55% growth per year between 2020-2030 [2]. From this data we can analyze exponential growth of the data traffic of mobile networks. The reason this is an issue for mobile networks, is that due to the excessive volume of the traffic and data, bandwidth is used up and transmission speeds are lowered. Thus, this contributes directly to the network being unable to handle and predict traffic as well as their accompanying detriments to the speed of the network. The reason this is significant to this review, is that it directly lowers the reliability of the network, pointing to a need for a digital twin to accommodate for the drastic increase in data traffic in the future.

2) Operations and Maintenance: Furthermore, there is a massive demand in operations and maintenance of cloud services and networks, to upkeep a strong network. Operators prioritize increasing the quality of the network to provide a better experience for users. There is a large issue with this, however. There is a variety of developers for networks and data is separated rather than in a unified location [3]. What does this mean for the way networks are operated and maintained? From this structure we can see that there is a lack of a constant design in these networks due to different developers. This causes systems to be separate and thus more difficult to maintain due to having different composition. Additionally, With data separated it becomes more difficult to analyze data which reduces the ability to prevent outages and find the reason for poor network quality.

3) Server Outages and Cloud Computing: A large challenge for networks is server outages. They have a large impact on users as an outage leads to downtime of the network and thus an unusable one. These outages are caused by a multitude of factors, such as hardware issues, design issues, and operations errors. The real issue, however, lies in the root cause of the outage being unknown. This leads to the outage being repeated in the future, which is bad for both businesses and users alike [4]. From this we can see that identifying the cause of an outage is incredibly important, as without it the network will often experience downtime due to the network being brought back online rather than understanding its weakness.

The use of cloud computing is everywhere, from services such as Amazon, Google, and a multitude of streaming platforms. The modern internet is run on cloud computing. This means that the use of large data centers with networks of servers hosted on the internet, must have full availability and accessibility for the billions of users. Due to the sheer scale of cloud computing services, a single outage for minutes can cause drastic drops in stock prices and revenue for businesses. From a study, between 32 cloud services, near 600 outages occurred between 2009 and 2015 [5]. From these statistics, we can see that reliability is not guaranteed, especially when it comes to full availability for users. Furthermore, it is important to prevent these outages from occurring to improve user experience and reduce business damages. The use and maintenance of complex servers with large data centers proves incredibly challenging with the number of outages, pointing to a need for a stronger maintenance system.

B. Network Digital Twin

1) Improving reliability: How does a network digital twin work to combat these obstacles? A NDT will essentially mimic a physical network in a virtual environment, and communicate using a closed loop control system. What this means is the physical network sends any relevant information about itself. Namely, the latency, bandwidth, packet loss, and data traffic. This data is incredibly important to the success of the network as these metrics allow for the operator to assess the given state of the network at real time. The NDT can then respond to this information with commands [6]. By using a digital twin, it can simplify the complex designs found in networks by laying out a strong visual, while providing easier means to maintain the network. Furthermore, by receiving data in real time, the operator is able to assess the status of the network and respond efficiently.

2) Architecture: The architecture of a NDT is composed of the dataset, the model itself, and a network optimizer. The dataset, composed of all network data, is used to construct the model, though it can also be built using deep learning. The model continues to use the network data as input, allowing the network operator (e.g. AI), to alter any values and analyze resulting output for testing that could otherwise not be accomplished without the digital twin. This is due to the NDT being a virtual representation rather than the actual physical network. The final piece of the architecture is the network optimizer, which simply allows for the NDT to search for the best way to operate the network [7]. What can we analyze from this architecture is the benefit of safe testing from a virtual environment of the network. This means if testing causes a massive crash or lowers the network quality substantially, it will not actually have an impact on the physical network, instead allowing for the digital twin to learn from the tests without any large drawbacks. This improves both maintenance and reliability massively.

3) Challenges: Using a NDT does not come without challenges in the form of requirements. In the context of a network digital twin, the challenges are storage, latency, and security. Storage is extremely important when using a digital twin as there is large amounts of data needing to be stored, often in datasets. The means of storing this data can prove challenging due to expenses and adding another layer of maintenance for the storage system, whether it be physical or cloud storage. Low latency is a requirement for the NDT to receive data in real time from the physical network. Security must be implemented to protect the data being stored. This is often found in digital twins today in the form of public key cryptography and standard AES or DES encryption [8]. From this information, we can see that the process of implementation is the primary challenge. It is important to ensure that the environment is supported well using high speed cables (e.g. fibre optic), data compression, and large but safe data storage. While a NDT is a powerful tool, ensuring that the digital twin is optimized and able to utilize data in real time is the first and arguably most important step to ensuring the physical network is optimized.

By utilizing a NDT, we can better monitor, test, and control physical system via simulating the physical status virtually. This virtual simulation lets us not only provide a stronger visualization of the physical network, but a larger capacity for analyzing data and accompanying irregularities. [10]

C. Implementing AI

1) AI Function: Using artificial intelligence for a network digital twin helps in a multitude of ways. For example, it works to help in the decision making process in which commands are sent back to the physical network. This process becomes automated and allows for a more efficient communication between the NDT and the physical network. The primary function of an AI in a NDT is to use the data received from the physical network to optimize the parameters. Using machine learning algorithms, the data can be processed and analyzed for recognition of trends in the context of the network quality. The NDT is able to simulate through all test cases in the virtual network to maximize the quality of service of the actual network. In addition to this, the AI can learn to predict crashes or potential harms to the network from both the data trends as well as the test cases. This allows for the network to prepare to negate those through its commands, or even fully preventing them all together prior to their occurrence using prediction [9].

2) Why do AI work so well with NDTs?: Aside from the actual function of the AI in NDTs, it may be questioned why they go hand in hand together so well to begin with. Simply, the way a NDT works at its core is by using data. By its very nature its a data driven support system, connecting a physical and virtual network to allow for simple maintenance and testing. Artificial intelligence is designed to work from data to learn, adapt, respond, and predict. Including an AI in a NDT fills in a gap that takes the network from well supported to fully optimized. The NDT becomes as strong as the algorithm used in its data analysis.

What can be concluded about using AI in a network digital twin? It allows the NDT to be extremely solid and reliable. Without the use of an AI, a NDT would potentially be unable to deal with or even catch disruptions to the network, particularly not unexpectedly. When it comes to the challenges faced by new technology and maintaining a quality network, not only using a digital twin, but supplementing it with an AI provides an unparalleled level of support.

III. Conclusion

There is a vast array of new technologies, namely cloud computing services, relying on networks and servers. These networks do not run optimally and suffer from unexpected outages and lowered transmission speeds. Often, it is due to the large scale of data traffic flowing onto the servers. This leads to users experiencing downtime and businesses suffering as a result. Through the use of a network digital twin that is implemented to its full potential, however, we can better maintain and test these networks in a secure environment and prevent further outages while increasing the quality of the network. In addition, by utilizing an artificial intelligence in the network digital twin, we can make these processes more efficient, accurate, and allow for prediction prior to unexpected challenges to the network, such as large data traffic or outages.

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References

[1] M. M. Rathore, S. A. Shah, D. Shukla, E. Bentafat, and S. Bakiras, "The role of ai, machine learning, and big data in digital twinning: A systematic literature review, challenges, and opportunities," *IEEE Access*, vol. 9, pp. 32030–32052, 2021.

[2] F. Tariq, M. Khandaker, K.-K. Wong, M. Imran, M. Bennis, and m. Debbah, "A speculative study on 6g," 02 2019.

[3] X. Zhang, X. Cheng, L. Wang, W. Wang, K. Yang, and Y. Cao, "Operation and maintenance system architecture design and practice for cloud-network integration," in *Journal of Physics: Conference Series*, vol. 2625, p. 012003, IOP Publishing, 2023.

[4] A. Wood, "Predicting client/server availability," *Computer*, vol. 28, no. 4, pp. 41–48, 1995.

[5] H. S. Gunawi, M. Hao, R. O. Suminto, A. Laksono, A. D. Satria, J. Adityatama, and K. J. Eliazar, "Why does the cloud stop computing? lessons from hundreds of service outages," in *Proceedings of the Seventh ACM Symposium on Cloud Computing*, pp. 1–16, 2016.

[6] M. Groshev, C. Guimarães, J. Martín-Pérez, and A. de la Oliva, "Toward intelligent cyber-physical systems: Digital twin meets artificial intelligence," *IEEE Communications Magazine*, vol. 59, no. 8, pp. 14–20, 2021.

[7] P. Almasan, M. Ferriol-Galmés, J. Paillisse, J. Suárez-Varela, D. Perino, D. López, A. A. P. Perales, P. Harvey, L. Ciavaglia, L. Wong, *et al.*, "Digital twin network: Opportunities and challenges," *arXiv preprint arXiv:2201.01144*, 2022.

[8] M. Mashaly, "Connecting the twins: A review on digital twin technology & its networking requirements," *Procedia Computer Science*, vol. 184, pp. 299–305, 2021.

[9] S. H. Khajavi, N. H. Motlagh, A. Jaribion, L. C. Werner, and J. Holmström, "Digital twin: Vision, benefits, boundaries, and creation for buildings," *IEEE Access*, vol. 7, pp. 147406–147419, 2019.

[10] H. Ahmadi, A. Nag, Z. Khar, K. Sayrafian, and S. Rahardja, "Networked twins and twins of networks: An overview on the relationship between digital twins and 6g," *IEEE Communications Standards Magazine*, vol. 5, no. 4, pp. 154–160, 2021.