CPS and 5G

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Contents

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Abstract: Cyber-Physical Systems (CPS) are integrated systems where physical processes interact closely with computation and communication technologies. As these systems become more prevalent in areas such as autonomous vehicles, smart manufacturing, and healthcare, the demand for fast, reliable, and scalable communication grows. Fifth-generation (5G) mobile networks offer key features like ultra-low latency, high bandwidth, and massive device connectivity, making them a strong enabler for the future of CPS. This research provides an overview of CPS and 5G technologies, explores their integration, highlights the benefits of combining them, and discusses the challenges and future directions. The goal is to clarify how 5G can enhance CPS performance and open new possibilities for real-time, intelligent, and connected systems.

1 Introduction

With the increasing number of sensors worldwide connected to the Internet,Where it was made possible by the current fast advances of technology. Furthermore, the massive number of physical objects such as embedded devices, smartphones, smart tablets, sensors,and actuators shaped the notion of cyber-physical systems (CPS). CPS is mainly an interconnected physical object and a Cyber system more like a simulation. What facilitates the connection between cyber-physical different systems is the Internet of Things [At17]. One of the greatest challenges of connecting the cyber system with the physical component is the transmission of data and the connection between them. With the recent rise of 5G technology, nearly real-time communication between systems became achievable [Ra23]

2 Background

2.1 Cyber-Physical Systems

CPS is the foundation of Internet of Things and it forms the foundation for Industry 4.0. A real life example for CPS is the mobile phone. With technological advancements, phones offer an extensive set of usages which have completely changed the early principal of mobile phones. [Me19]

CPS has various uses, They are used in transportation for example in public transportation to manage vehicle charging and monitoring traffic. Moreover, it is used in Intelligent buildings to monitor and control HVAC systems, electrical and safety systems. [Me19] In summary, Cyber-Physical systems are complex, physically aware systems that integrates with physical hardware and cyber computing. The system as a whole, observes, communicates and control aspects of the physical system. [Gu14]

2.2 5G Technology

5G is the fifth generation of wireless communications supporting cellular data networks. What makes 5G impactful to many specializations is its ultra low to latency and the support

for huge amounts of data to be transported at high speeds [Ra20]. 5G offers high-speed internet connectivity, a great bandwidth and unlocks the ability to stream UHD media in nearly real-time. There are many services that made use of these features, such as massive machine-to-machine communications, virtual reality online meeting rooms, smart homes, and more [Da22].

Moreover, 5G enhances mobile broadband, and machine-type communications [Sa23].Additionally, The traditional mobile networks employ the one-size-fits-all approach regardless of the service networking requirements. While the concept of network slicing was introduced in 5G networks to address this current issue [CA25].

3 5G enabling technologies for Cyber-Physical systems

CPS systems require real-time processing and decision making which often needs communication between the system components [WGL19]. 5G technology enables this seamless communication by introducing Ultra-reliable and low-latency communication also known as (URLLC). This approach enables low latency transmission of small payloads with a very high reliability [Po18]. Another implemented technology in 5G is eMBB which is short for enhanced mobile broadband this supports the connection to be stable with a very high peak data rates. The third enabling technology in 5G that would benefit the integration with CPS systems the most is massive machine-type communications also known as (mMTC). This enables new use cases and new CPS systems integrating the 5G technology, like, automotive industries, energy, eHealth and entertainment. [Tr18].

4 Ask ChatGPT

4.1 ChatGPT

Cyber-Physical Systems (CPS) integrate computation, networking, and physical processes to enable real-time monitoring and control. These systems underpin technologies such as autonomous vehicles, industrial automation, and smart healthcare. However, their effectiveness is often constrained by limitations in legacy communication infrastructures, particularly in terms of latency, reliability, and scalability.

Fifth-generation (5G) networks address these constraints through ultra-reliable low-latency communication, enhanced broadband, and support for massive device connectivity. These capabilities enable CPS to function with greater precision and responsiveness. Sub-millisecond latency allows for time-critical applications like remote surgery and autonomous driving. High data throughput supports tasks such as real-time video analytics, while dense device connectivity facilitates large-scale IoT deployments in smart cities and factories.

The integration of CPS with 5G brings both opportunities and challenges. While 5G enhances responsiveness and scalability, it also expands the attack surface, raising concerns around system security and privacy. Interoperability between heterogeneous CPS components and standardized 5G protocols remains complex. Moreover, dynamic environments require intelligent resource allocation and adaptive network management to ensure stability and efficiency.

Further research is needed to develop lightweight, secure communication protocols, AI-based network orchestration, and standardization frameworks that align CPS architectures with evolving 5G technologies. Addressing these challenges is essential for realizing the full potential of CPS in next-generation connected environments.

4.2 Scientific discussion

The previous subsection was generated by ChatGPT. It clearly discussed and gave an overview of the topic of CPS and 5G. At first, it introduced and defined both CPS and 5G technologies. Then it continued explaining the opportunities and challenges of integrating both. It concluded with the need for further research in this field and the need for addressing those challenges.

Though it was written nicely, I find that ChatGPT was not able to fully address the idea with a conceptual depth enough to explain what is exactly a CPS, instead, it just explained it as a simple network control system. It also lacks Technical precision, due to the fact it didn't mention any references. In other terms we can not be sure about the sources used for this generation which might be fake. There is also an inaccuracy when mentioning that 5G networks provide sub-millisecond latency. According to [Ag22, GS19] , the current state of 5G networks have a latency between 1 ms to 10 ms, though it is expected theoretically to reach the sub-millisecond latency when 5G technology and CPS integration are more developed but there is no practical proof until this moment. [GS19]. Moreover , regarding the challenges, it was not mentioned that one of the biggest challenges now is upgrading the current CPS technology to leverage 5G capabilities [Ko24].

5 Applications of CPS and 5G integration

Integrating both CPS and 5G technologies opens the possibility of many industries to develop more advanced systems leveraging the 5G connectivity. Though this technology is still new, already many of the industry fields started integrating this technologies [Tr18].

5.1 Automotive Industry

With the yearly huge increase in automotives, transportation solutions already implemented cannot keep up with the growing traffic congestion and problems of today. Many solutions

done were not able to fully address the issue of congestions and traffic problems. The ultimate goal is to develop Intelligent Transportation Systems. This will not just make travelling quicker but also safer and more comfortable [Ra23].

5G allow high speed connectivity between vehicles, which will decrease the number of accidents. 5G connection would allow the walkers and the infrastructure to communicate with each other in both directions.This would create a cyber-physical system of global traffic control, in which will exchange messages about the traffic conditions. [Ra23].

When integrating both systems, it is expected to have Intelligent systems that is able to path plan and autonomous control of vehicles. It will allow the vehicles to communicate with nearly 1 ms latency to keep the system informed about current congestions and even probable future congestions. This will allow the autonomous path planning system to drive into alternative roads to avoid more congestions and making the trip easier and faster [Ra23, FCS17].

Additionally, Integrating 5G with CPS systems in automotive field would allow an easier, safer vehicular platoon control. Platooning would greatly enhance highway safety, fuel consumption and increase traffic stability. In this scenario, each joining self-driving vehicle must individually take decisions of its on dynamics and while keeping in mind to have the least effect on the stability of the entire vehicles platoon. Those decisions must be nearly in real-time and must be communicated thoroughly to the other vehicles in the platoon to ensure safety of the entire platoon. In a platoon, mostly all vehicles collects similar images and measurements. Those data should be shared among the other vehicles to reduce the computational load of each vehicle [FCS17, Tr18].

5.2 Digital Twins

Physical Simulation have been used extensively in production to analyse physical effects of real world but in a virtual simulated world. it is based on a physics engine, which is a software platform that contains reusable resources to compute specific physical interactions on the materials and bodies [Za21].

There is mainly 3 main functionalities for Digital Twins [**?**].

- **prediction:** The system should be able to predict the real-world system behaviour without it yet taking place.
- **Monitoring and control:** The system should be able to observe the physical system and adjust its parameters using the data form the digital twin in real-time.
- **Diagnosis:** The system should analyse historical and real-time data to identify and explain failures in the system after they occur.

In other words, Digital twins is a link between physical and virtual world in cyber-physical production systems. In order to achieve those goals and make the system reliable, software, hardware and communications technological requirements needs to be met [Me23]. On the communications side, the data transmission between the physical model and the digital model should be wireless. Moreover, Those systems requires a really low latency that does not exceed 50 ms just to achieve monitoring requirements and below 1 ms for motion control [Ho19]. Also, communication must be extremely reliable with a maximum of 30 seconds downtime per year. The network should also be scalable and flexible to allow high connectivity of many devices further integrated into a system. Hence, a network protocol that allows machine-to-machine like the ones currently developed in 5G architecture must be utilized [Me23]

6 Challenges

7 Future Work

8 Conclusion

9 Declaration of originality

I, Mohamed Amer, herewith declare that I have composed the present paper and work by myself and without the use of any other than the cited sources and aids. Sentences or parts of sentences quoted literally are marked as such; other references with regard to the statement and scope are indicated by full details of the publications concerned. The paper and work in the same or similar form have not been submitted to any examination body and have not been published. This paper was not yet, even in part, used in another examination or as a course performance. I agree that my work may be checked by a plagiarism checker.

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