

Technology forecasting with LLMs and Huggingface for Cyber-defence applications

Alexander Sternfeld¹, Prof. Dr. Andrei Kucharavy¹, Prof. Dr. Dimitri Percia David¹, Prof. Dr. Julian Jang-Jaccard², Dr. Alain Mermoud²

¹Reliable Information Lab, HES-SO Valais-Wallis, Switzerland

²Cyber-Defence Campus, armasuisse, Science and Technology, Thun, Switzerland



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Whois

Alexander Sternfeld



- Associate researcher
@ Reliable Information Lab
- Former intern
@ Cyber-defence Campus, armasuisse
- Data science graduate
@ EPFL



What is this talk about?

- For **rapidly developing technologies**, technology forecasting through expert opinions becomes difficult
- We developed the **agentic AI** framework *PromptSight* that supports **early-stage exploration** of emerging technologies
- *Saluting Face*: how a **defence-specific** variant of Huggingface could aid defence partners in leveraging AI

Today

- **Technology forecasting**
 - Technology forecasting and machine learning
 - PromptSight: how does it work?
 - Results
 - Limitations
 - Future directions
- ***Saluting Face: Huggingface for Cyber-defence applications***
 - Why develop such a platform?
 - Next steps
- Demo of PromptSight and Q&A

Technology forecasting and ML - 1

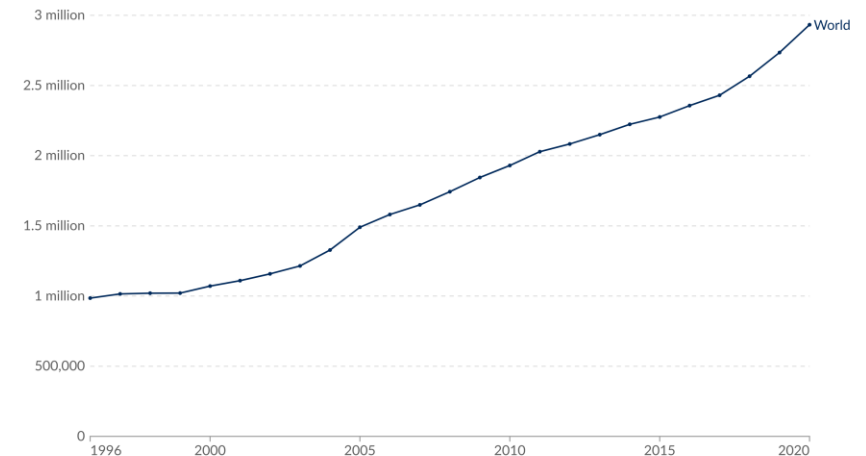
- We focus on **fast-moving technologies** (e.g. LLMs)
→ difficult to execute traditional forecasting methods such as Delphi analysis
- Large quantities of rapidly evolving information further complicate expert-based reviews



Annual articles published in scientific and technical journals

Includes physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

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Data source: National Science Foundation (via World Bank) (2025)
Note: Articles are counted by the country of the author's institution.

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Technology forecasting and ML – 2

- Recent research aims at processing this information with ML and NLP



Early identification of emerging technologies: A machine learning approach using multiple patent indicators

Changyong Lee ^a, Ohjin Kwon ^b, Myeongjung Kim ^a, Daeil Kwon ^c

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A Bibliometric Analysis of Text Mining: Exploring the Use of Natural Language Processing in Social Media Research

by Andra Sandu ¹, Liviu-Adrian Coffas ^{1,*}, Aurelia Stănescu ² and Camelia Delcea ¹

From Fiction to Forecast: Leveraging LLM-Enhanced Models and Science Fiction for Innovative Technology Predictions

Publisher: IEEE Cite This PDF

Chen Jin ; Zhang Keren ; Zhu Ziqin ; Lin Jiawei ; Zhang Yilun All Authors

1 Cites in Paper
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Our past work in this domain

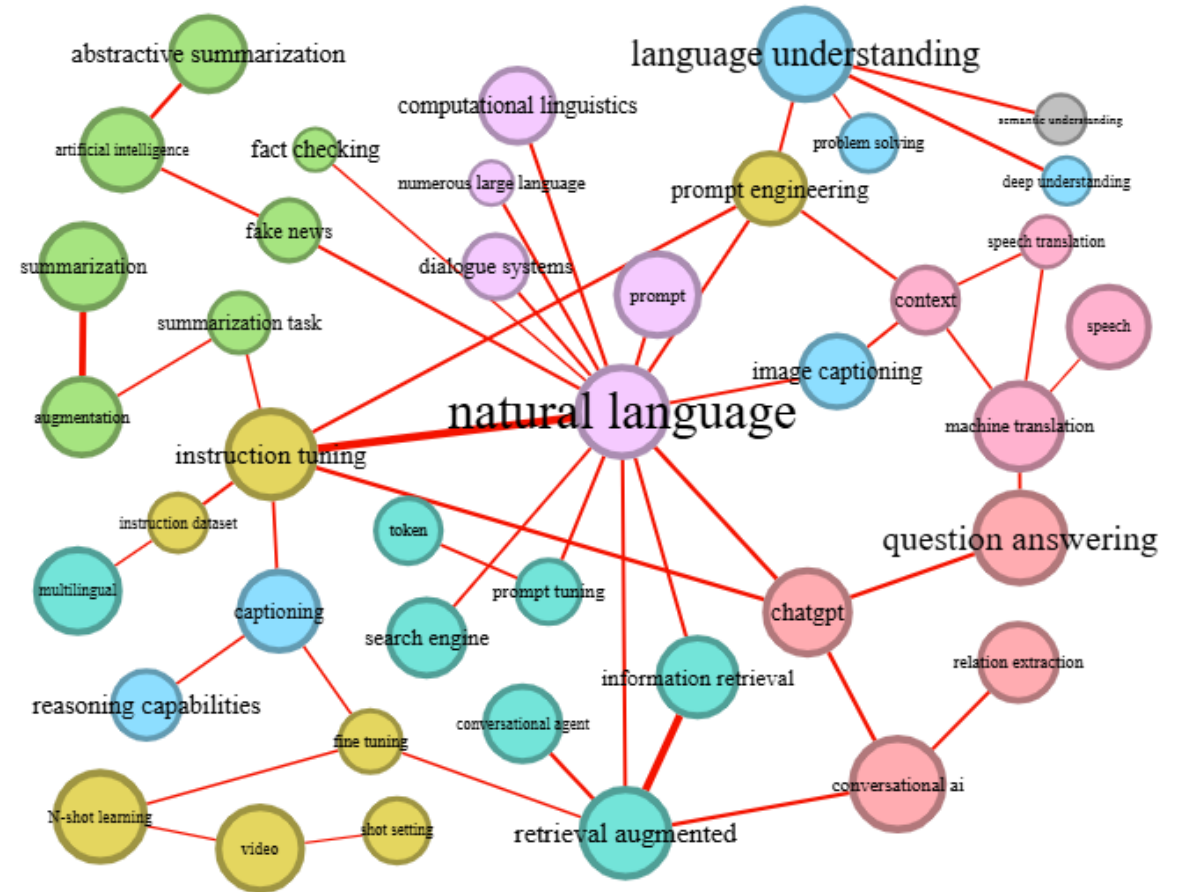
- Development of **triple extraction** method from scientific papers and patents
→ network of **semantic entities**
- Leverage this network for insights in **emerging and converging technologies**

Monitoring Transformative Technological Convergence Through LLM-Extracted Semantic Entity Triple Graph

Alexander Sternfeld¹, Andrei Kucharavy¹, Dimitri Percia David¹, Alain Mermoud², Julian Jang-Jaccard² and Nathan Monnet²

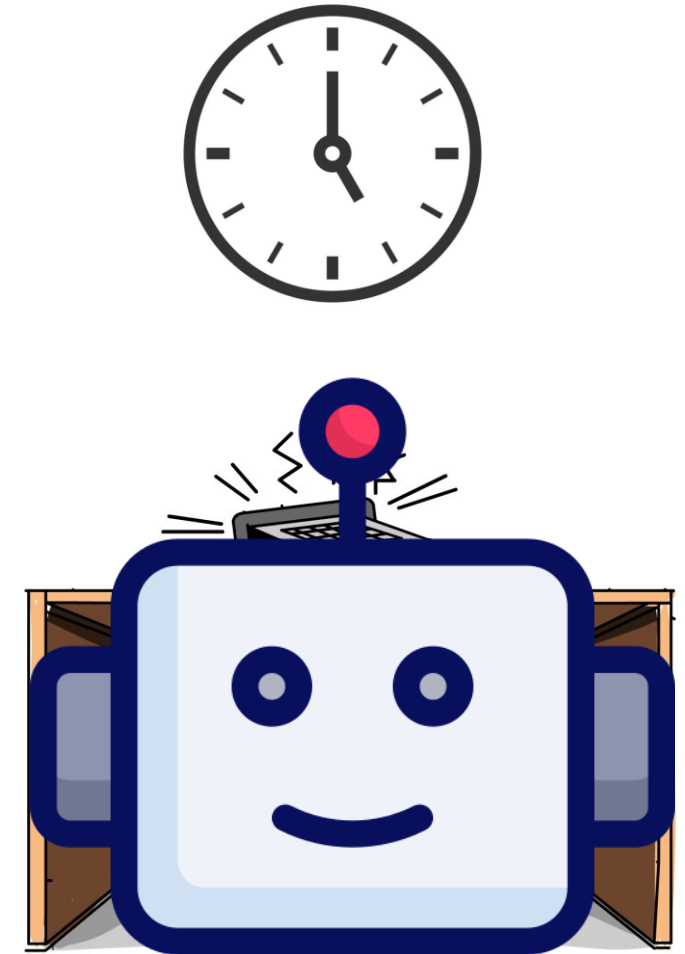
¹ Cyber-Defence Campus, armasuisse, Science and Technology, Thun, Switzerland

² Institute of Entrepreneurship & Management, HES-SO Valais-Wallis



This is nice, but...

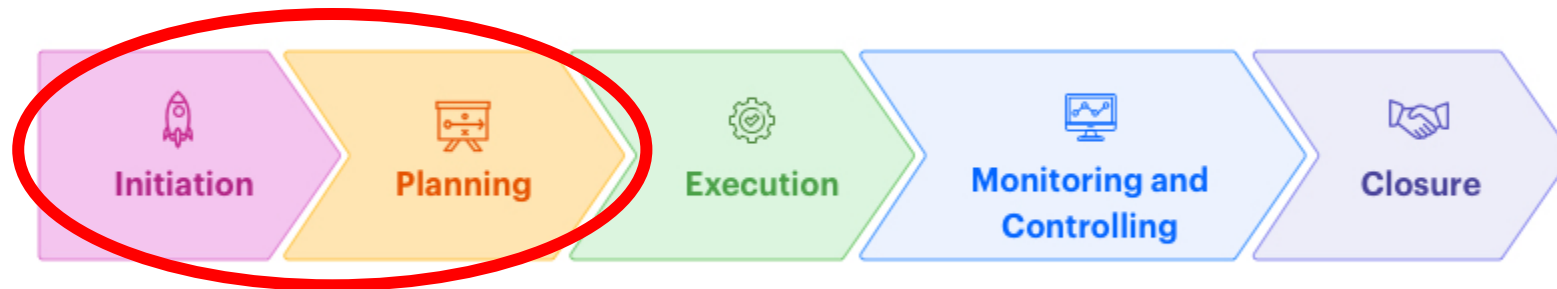
- Such methods are **computationally expensive** and **not readily available**
→ need to process a large amount of data
- What if we are in early stages of exploration and want to get an initial idea of the field?



LLM usage is under-explored

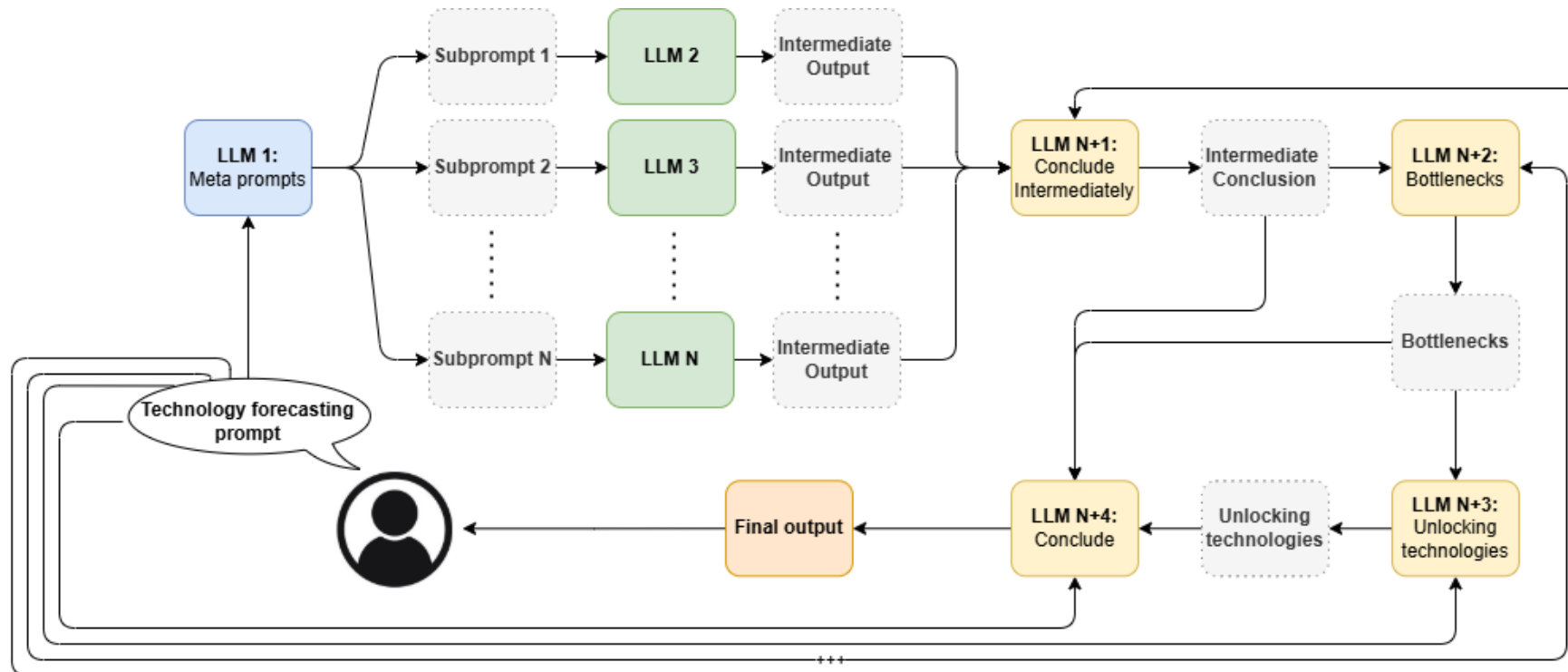
- The performance of LLMs is highly dependent on the **prompting strategy**
- We found that directly prompting a LLM results in a forecast **lacking depth and breadth**

→ **Contribution:** we provide an *agentic AI* framework for technology forecasting



PromptSight

- Prompts are split into **subquestions**, then **bottlenecks** and **unlocking** technologies are identified
- The final output is a **comprehensive** technology overview



Example – splitting into sub-prompts

- Prompt:

*What will be the three most important and impactful technologies in the field of **satellite communication** over the next five years?*

- Split into sub-prompts:

- You are doing a technology forecasting research project. Your task is to identify **current trends and developments** in the field of satellite communication, and provide an overview of the most important technologies that are currently being used.
- You ... task is to research and analyze emerging technologies in the field of satellite communication, and provide a list of **new technologies** that are being developed and have the potential to be impactful in the next five years.
- You ... task is to evaluate and rank the potential impact of different technologies in the field of satellite communication over the next five years, and identify the **top three** most important and **impactful technologies** that will shape the future of the field

Example – bottlenecks and unlocking technologies

- Several examples:
 - *LEO constellations*: Interference and congestion → satellite traffic management systems
 - *High-Throughput satellites*: High production costs → Modular and 3D-printed Satellite manufacturing technologies
 - *5G and 6G integration*: Latency and synchronization → Low-Latency Satellite Communication Protocols
 - *5G and 6G integration*: Security and authentication → Quantum-Resistant Encryption

Final conclusion

- Enhances the intermediate conclusion with the bottlenecks and unlocking technologies
- More elaborate, comprehensive and specific

In conclusion, the next five years will be a period of significant innovation and growth in the field of satellite communication, driven by the development and deployment of LEO constellations, HTS, and 5G and 6G integration. While these technologies face significant challenges, emerging technologies such as advanced satellite traffic management systems, modular and 3D-printed satellite manufacturing technologies, and quantum-resistant encryption and low-latency satellite communication protocols are being developed to unlock their full potential. As these technologies continue to evolve and mature, we can expect to see significant improvements in global connectivity, low latency, and high-speed data services, driving the development of new applications and services that will shape the future of the industry. The convergence of satellite and terrestrial networks will create new opportunities for innovation and growth, enabling the development of new use cases and applications that require low latency, high-speed, and global coverage. Ultimately, the future of satellite communication is exciting and promising, with significant potential for growth, innovation, and transformation.

But do we improve upon existing methods?

- We made two comparisons
 - Compare to baseline LLM → in paper accepted at EEKE `25
 - Compare to an existing Delphi method

Comparison to traditional baseline - 0

- For a proper validation we need to compare to a traditional forecasting method



The future of artificial intelligence: Insights from recent Delphi studies

Ido Alon^{a,*}, Hazar Haidar^b, Ali Haidar^c, José Guimón^a

^a Department of Development Economics, Autonomous University of Madrid, Spain

^b Ethics Programs, Department of Letters and Humanities, University of Quebec at Rimouski, Rimouski, Québec, Canada

^c ESCP Business School, Madrid, Spain

Comparison to traditional baseline - 1

- Forecast on AI in healthcare:
 - **Delphi:** Improved diagnostic accuracy, enhanced patient care and access, operational efficiency, educational advancements, ethical and data governance challenges
 - LLM insights not in Delphi: higher focus on *computer vision* and *patient engagement and support*
- Similar findings for AI in journalism / photography

Limitations and going further

- **Hallucinations and climate effects**
 - Hallucination is an *inevitable risk*, however, we did not see any signs of it in our experiments.
 - Each run is computationally expensive, but the framework is meant for *high-quality* forecasts, not mass deployment
- **Retrieval-augmented generation and semantic triples**
 - We can improve our framework by incorporating RAG through a knowledge base, such as the semantic triple graph we developed.
 - Through this added knowledge, forecasts can become more specific and inform the user on the time and location of new emerging technologies

Saluting Face: a model-sharing and benchmarking platform for cyber-defence applications

Use cases of generative AI in defence

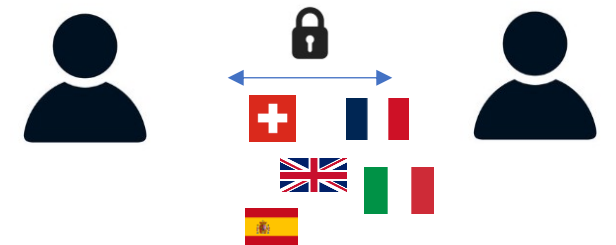
- With the increasing power of generative AI and general ML methods, there is a rise in interest in potential use cases for **defence applications**
- Examples of such **use cases** are: threat detection, secure communication, training scenario generation, logistics optimization



Project Maven



Logistics and ML



Secure multilingual communication

What is Huggingface?

- Leading open-source platform for AI models
- Contains thousands of pre-trained models, datasets and benchmarks
- Development of tools for training, inference and deployment of models (transformers)



Hugging Face

Saluting Face: a defence-specific model sharing platform

- Why set up such a platform?
 - Share models and datasets among defence partners
 - Develop benchmarks for defence-specific tasks
 - Foster multinational collaboration
 - Track the usage of various models and datasets
- Why not simply use Huggingface?
 - Defense applications have an inherent adversarial context
 - The platform has to be secure and controlled
 - Governance of such a platform should not be with a corporate



Risk profile



Adversarial misuse
→ White- or black-box



Data or model leakage



Data sensitivity



Regulatory differences

Next steps

- Contact defense partners and potential stakeholders
 - SAF (Swiss Armed Forces), Stab Kdo Cy, AStab, Kdo Op, Swiss Innovation Forces
- Identify high-value use-cases
 - Ideally low-risk and high-benefit applications
- Map data availability and data sharing options
- Develop risk mitigation strategies

Demo of PromptSight



Dimitri **Percia David**
Associate professor UAS



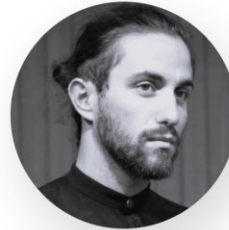
Andrei **Kucharavy**
Assistant professor UAS



Anastasiia
Kucherenko
Research associate UAS



Loïc **Maréchal**
Research associate UAS



Matteo **Monti**
Research associate UAS



Alexander **Sternfeld**
Research associate UAS



Sherine **Seppey**
Economic associate



Gen Learning Center:
<https://tinyurl.com/hevs-gen-learning>



Cyber-defence campus:
<https://www.cyd-campus.admin.ch/en>

Connect with us

LinkedIn: [\[\]/in/alexander-sternfeld](#)
Mail: alexander.sternfeld@hevs.ch

Baseline result

Based on industry trends, research, and development, the three most important and impactful technologies in the field of satellite communication over the next five years are likely to be:

1. **Low Earth Orbit (LEO) Constellations and Mega-Constellations:** The launch of numerous LEO constellations, such as Starlink, OneWeb, and Amazon's Kuiper Systems, will revolutionize satellite communication. These constellations will provide global coverage, high-speed, and low-latency connectivity, enabling a wide range of applications, including:
 - Broadband internet access for remote and underserved areas
 - IoT (Internet of Things) connectivity
 - 5G and 6G backhaul
 - Maritime and aviation communications
 - Earth observation and remote sensing
2. **Quantum Satellite Communications and Quantum Key Distribution (QKD):** The integration of quantum technology into satellite communication will provide ultra-secure and reliable data transmission. QKD will enable:
 - Secure key exchange and encryption for sensitive data
 - Protection against cyber threats and eavesdropping
 - Secure communication for government, financial, and military applications
 - Enhanced security for IoT and 5G networks
 - Potential for secure communication in space exploration and deep space missions
3. **Phased Array Antennas and Advanced Beamforming Technologies**:** The development

3. **Phased Array Antennas and Advanced Beamforming Technologies**:** The development of phased array antennas and advanced beamforming technologies will significantly improve satellite communication performance, enabling:

- Higher data rates and throughput
- Increased spectral efficiency and reduced interference
- Improved beam steering and shaping for enhanced coverage and capacity
- Better support for multiple frequency bands and satellite constellations
- Enhanced mobility and flexibility for airborne and maritime applications

These technologies will have a significant impact on the satellite communication industry, driving innovation, and enabling new applications and services. They will also address some of the current challenges, such as latency, security, and capacity, and will pave the way for the widespread adoption of satellite communication in various industries, including telecommunications, finance, government, and transportation.

Other notable technologies that may also have a significant impact on the satellite communication industry in the next five years include:

- Advanced propulsion systems, such as electric propulsion and Hall effect thrusters
- In-orbit servicing and assembly
- Satellite-based Earth observation and remote sensing
- 5G and 6G integration with satellite communication
- Artificial intelligence (AI) and machine learning (ML) for satellite communication and network management

However, the three technologies mentioned above are expected to have the most significant and immediate impact on the industry, driving innovation, and enabling new applications and services.

Final conclusion from our framework

The field of satellite communication is undergoing significant transformations, driven by technological advancements, increasing demand for global connectivity, and the need for more efficient and cost-effective solutions. Over the next five years, several technologies are expected to play a crucial role in shaping the future of the industry. Based on current trends and developments, emerging technologies, and their potential impact, the three most important and impactful technologies in the field of satellite communication are expected to be Low Earth Orbit (LEO) constellations, High-Throughput Satellites (HTS), and 5G and 6G integration.

LEO constellations, comprising a large number of satellites in low Earth orbit, aim to provide global coverage with lower latency and higher speeds compared to traditional geostationary satellites. Companies like SpaceX, OneWeb, and Amazon's Kuiper Systems are leading the development of LEO constellations, which are expected to revolutionize satellite broadband services. The impact of LEO constellations will be felt across various industries, including telecommunications, aviation, maritime, and IoT, enabling new applications and services such as global connectivity, remote sensing, and satellite-based IoT.

High-Throughput Satellites (HTS) are designed to provide higher data throughput rates, making them ideal for applications requiring high bandwidth such as broadband internet access, video transmission, and mobile backhaul. The deployment of HTS has been increasing, with many operators launching new HTS systems to cater to the growing demand for high-speed data services. The next generation of HTS will enable faster and more efficient connectivity, supporting applications such as broadband internet, video streaming, and cloud computing.

The integration of satellite communication with 5G and 6G wireless networks will enable seamless and ubiquitous connectivity, supporting a wide range of applications, including IoT, autonomous vehicles, and smart cities. This integration will also facilitate the development of new use cases, such as satellite-based 5G networks and 6G-enabled satellite communication. The convergence of satellite and terrestrial networks will create new opportunities for innovation and growth in the industry, driving the development of new services and applications that require low latency, high-speed, and global coverage.

Other technologies, such as quantum communication, phased array antennas, and in-orbit servicing and manufacturing, are also expected to play important roles in the satellite communication industry over the next five years. Quantum communication, which uses quantum mechanics to enable secure and reliable communication over long distances, has the potential to revolutionize the way we communicate, enabling secure data transfer and communication for sensitive applications. Phased array antennas, which use multiple small antennas to steer and shape the beam of radio waves, will improve the efficiency and flexibility of satellite communication systems, enabling faster and more reliable communication. In-orbit servicing and manufacturing, which involves performing repairs, upgrades, or refueling of satellites in space, will extend the life of satellites, reduce the cost of satellite development and launch, and enable new applications such as satellite-based manufacturing.

However, the development and deployment of these technologies are not without challenges. LEO constellations, for instance, face regulatory challenges, interference and congestion, and high costs. High-Throughput Satellites (HTS) are hindered by high production costs, ground segment limitations, and spectrum allocation and management issues. The integration of satellite communication with 5G and 6G wireless networks is also faced with challenges such as standardization and interoperability, latency and synchronization, and security and authentication. To overcome these bottlenecks, emerging technologies are being developed to unlock the full potential of LEO constellations, HTS, and 5G and 6G integration.

For LEO constellations, advanced satellite traffic management systems and automated regulatory compliance tools are being developed to mitigate interference and congestion, and simplify the process of ensuring compliance with regulatory requirements. These technologies will enable the efficient management of the increasing number of satellites in LEO, reducing the risk of radio frequency interference and congestion, and ensuring that operators can comply with regulatory requirements in a cost-effective and efficient manner. Additionally, advanced satellite traffic management systems will enable the optimization of satellite orbits, reducing the risk of collisions and improving the overall efficiency of LEO constellations.

For HTS, modular and 3D-printed satellite manufacturing technologies are being developed to reduce production costs and increase scalability, making HTS more accessible to smaller operators. These technologies will enable the rapid production of HTS, reducing the cost and time required to launch new satellites, and enabling operators to quickly respond to changing market demands. Furthermore, modular and 3D-printed satellite manufacturing technologies will enable the development of more complex and sophisticated HTS, with improved performance and capabilities.

For 5G and 6G integration, quantum-resistant encryption and low-latency satellite communication protocols are being developed to address security concerns and minimize the impact of satellite communication latency on 5G and 6G applications. Quantum-resistant encryption will provide secure and reliable communication over long distances, enabling the protection of sensitive data and applications. Low-latency satellite communication protocols will enable the optimization of satellite communication, reducing the latency and improving the performance of 5G and 6G applications. These technologies will enable the seamless integration of satellite communication with 5G and 6G wireless networks, supporting a wide range of applications and services that require low latency, high-speed, and global coverage.

In conclusion, the next five years will be a period of significant innovation and growth in the field of satellite communication, driven by the development and deployment of LEO constellations, HTS, and 5G and 6G integration. While these technologies face significant challenges, emerging technologies such as advanced satellite traffic management systems, modular and 3D-printed satellite manufacturing technologies, and quantum-resistant encryption and low-latency satellite communication protocols are being developed to unlock their full potential. As these technologies continue to evolve and mature, we can expect to see significant improvements in global connectivity, low latency, and high-speed data services, driving the development of new applications and services that will shape the future of the industry. The convergence of satellite and terrestrial networks will create new opportunities for innovation and growth, enabling the development of new use cases and applications that require low latency, high-speed, and global coverage. Ultimately, the future of satellite communication is exciting and promising, with significant potential for growth, innovation, and transformation.