Trends in AI Networks and 6th Generation Networks: A Systematic Literature Review

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ABSTRACT

6G Integration of intelligent communication, sensing, computing and automated controls is expected in 6G systems. Research on these capabilities is fragmented. Objective: This article reviews the recent research on Artificial Intelligence (AI) networks and 6G networks between 2020 and 2025. The analysis includes positive impacts, maturity level, challenges for adoption, research gaps, and trends. Method: A systematic review of the literature was conducted following a documented protocol. Purposive eligibility was used to select studies from the total set. The stages of the review were organized using the adapted Waterfall Model. Study identification, screening, eligibility and inclusion were reported according to the PRISMA 2020 Guidelines. The project documents of 38 included studies formed the source of evidence; they do not report verified numeric totals for each of the previous selection stages. Summary and thematic synthesis of data were performed. Results: The 8 studies each representing the themes of the architecture of AI-native networks and automation of 6G networks (21.1% of the total) were the largest thematic groupings. A taxonomy and qualitative assessment of the reviewed literature showed that deployment validation is less developed compared to conceptual architecture. The major barriers identified in the literature include testbed scarcity, security and privacy, model robustness, data, and governance. Conclusion: This review shows how research has transitioned to AI-native networks from AI-assisted networks. Governance and integration across layers are required for lifecycle management, cross-layer security, and measurable task-oriented evaluation of 6G networks. Zero-energy devices are a proposed research extension, not a major finding of the 38 studies reviewed in this article.

Keywords: AI-native networks; 6G networks; Edge Intelligence; Semantic Communication; Systematic Literature Review

INTRODUCTION

Sixth generation (6G) cellular technology forecasts and prepares for the future demands and trends in communications. It identifies the enabling technologies and applications, and outlines the gaps in current capabilities to fulfil the desired functions (surveyed evidence) [1]. In the meantime, a clear case is building for using artificial intelligence (AI) to manage the challenges of future networks, such as traffic and resource management, as well as mobility and slicing. These functions may be integrated in the network and spread across different levels, including the edge and core of the network [2].

Until large-scale networking deployments become widespread, edge technologies and artificial intelligence (AI) may enable some transformative changes in the way we communicate by using learning and other related techniques (i.e., learning-based semantic communication) [3]. However, as more and more functions of the networking systems are controlled and managed by artificial intelligence, it may lead to a situation where people do not fully understand the inner workings of the networking systems, such as the reasons for system decisions and the key factors that influence the system outcomes. This will potentially constrain the functions of the system (e.g., AI explainability) [4].

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There is a clear imbalance in the presentation of AI in communication technologies (5G and beyond) and the related body of evidence on the readiness to integrate these technologies.

Some recent work has started to create visions and identify key enabler technologies for 6G, but assessing these visions still requires realistic evaluation environments [5]. Other recent work takes an integrative approach for AI-Native 6G and considers issues of Semantic Communication, Reconfigurable Intelligent Surfaces, Edge Intelligence and others, and hence does not address a major breakthrough in algorithms [6].

The aim of this study is to systematically review recently published literature on AI networks and 6G networks between the years 2020 and 2025.

This aim will be accomplished by answering the following questions:

1. What are the major trends in AI and 6G networks, as reflected by the literature reviewed?
2. What are the trends in the use of AI in the design, management, optimization and security of 6G networks, as well as in the provision of various services?
3. What is the integrating and enabling technologies in the area of AI-Native 6G?
4. What are the benefits, limitations, challenges and opportunities, as well as research gaps?

Motivation and contribution

This review brings together the multiple lines of evidence to determine the more developed research directions from the less developed and under-supported areas. It integrates a structured technical taxonomy and qualitative, theme-level appraisal, drawn from the project extraction and quality-assessment matrices. The methodology differentiates the organized review work from the reported study identification, screening, eligibility and inclusion, in line with PRISMA 2020. The primary focus is on performing a comparative synthesis of the AI-native themes of 6G, covering their function, evidence types and their barriers to and enablers for implementation. The review does not take the selected corpus as a representation of the entire 6G research in the world.

LITERATURE REVIEW

The literature describes the likely evolution of wireless systems, including more sophisticated service categorization, higher system capacity, more connectivity, more reliable and low-latency communications, as well as more integrated computation and communication. A survey of the 6G frontier presents the state-of-the art through representative use cases, identifies open requirements, describes enabling technologies and research challenges, and serves as a useful reference in defining the scope of research interests [1].

While these vision and survey papers lay down a baseline, they are primarily agenda-setting. The review regards 6G capabilities as research directions and reported design goals and objectives, rather than as assurances of commercialization and/or standardization.

AI-native networking and Edge intelligence

AI-native networking is more than embedding an isolated prediction model in a network. The aim is to encode learning, inference, decision making, and control in a network throughout its lifecycle. Edge intelligence, in this instance, means computing can be placed nearer to the user and network functions, thus removing the need to move the entire raw data to centralized resources, and meeting requirements for latency and responsiveness [2]. Federated learning, on the other hand, allows devices and infrastructure to collaborate without sharing raw data, but creates issues of data and model heterogeneity, communication overhead, and the straggler-device problem, among others [8]. Edge AI orchestration, in this case, means the integrated, coordinated placement of inference and training workloads, use of radio and edge computing resources, schedule model updates, and interact edge functions and network slices. The core of the network. The source project identifies digital twins to be useful in this respect, especially for testing and validating policies, performing integrated monitoring, and orchestration [12]. These functions should be assessed together rather than in isolation.

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The reviewed literature acknowledges the strategical value of Distributed Intelligence. The practical performance of any solution, however, relies on many factors including data and models available, the level of adaptation to different usage scenarios, available resources, how often models are updated, and the conditions under which the models are evaluated. The source project recognizes heterogeneous data, straggler devices, model drift and attacks, as well as communication costs, as key challenges. Consequently, future orchestration studies should compare resource and model-update policies against transparent baselines and evaluate Latency, communication and resource costs, resilience, and the ability to monitor, explain, and roll back automatic decisions. The focus of this study is not to determine which orchestration algorithm is the best, rather to provide a set of guidelines for future studies.

Semantic communication and 6G enabling technologies

Goal-oriented communication attempts to send the information necessary to complete a given task, as opposed to communicating with absolute accuracy at the bit level. Meaning can be learned and supported by deep-learning systems [3]. Determining the meaning, however, relies on the task and application domain, and thus, comparison of different studies is difficult when different tasks and criteria of success are applied. A better design would state the task and define the criteria for task success prior to testing. Performance of the communication system should also be measured under various conditions of the communication channel and the application domain. The source project recognizes the absence of common benchmarks and datasets as the main reason for the lack of comparison studies, and thus, claims for improvement of communication should be qualified until reproducible test cases are developed.

Evaluation of RIS, THz, and ISAC finds they serve as physical layer and environment enablers. Research in RIS focuses on programmable control of wireless propagation [9], and research in THz communication explores high-speed data communication considering hardware and propagation limitations [10]. ISAC integrates communication and sensing functions in future wireless systems [11]. Edge and federated intelligence facilitate distributed computing and learning [2] and [8], and digital twins facilitate simulation, monitoring and orchestration [12]. Integration with network slicing, hardware and edge resources, channel conditions and control, and data and network functions has also been explored [6].

Zero-energy Devices and the bound of the present review

In the reported thematic distribution, zero-energy devices have not been identified as a separate theme, and they are not present in the extraction matrix of the 38 included studies. Therefore, they are addressed in this review as a potential extension of the review scope, not as an established result of the included studies. Additional studies identified by a focused search including explicit keywords for zero-energy or zero-power devices and energy harvesting communications would be needed to address zero-energy devices in the context of AI-native 6G. If the evidence is found, the extraction would capture the assumptions made on the energy available to the device, the sensing and communicating functions, the computing constraints and the conditions under which the study was evaluated.]

Trustworthy AI and testbeds/operational readiness

Decisions around resource allocation, access control and routing (e.g. making a decision about which node to forward traffic to) can impact the safety and security of a network. AI can be deployed for such decisions. However, the AI has to be explainable, predictable and trustworthy. In cases where the AI behavior is unpredictable, its use should be restricted. Performance of AI alone should not be the basis of making such decisions. The research on AI in 6G has identified the importance of explainability and robustness. This supports that the decisions made by operators should be justifiable, auditable and manageable [4]. During the lifecycle of an AI system, there are several risks that may undermine trust in the system and compromise automated control. AI may take decisions that are not explainable.

Readiness also remains an evidence problem. While differentiating the nexus between 6G technologies, visions and testbeds may be a challenge, there have been systematic reviews in 6G technologies that identified gaps in

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clarity and reproducibility in the review process [6, 7].

This study fills a gap in the research by synthesizing the relative emphases of the main AI-native 6G themes and/or areas, differentiating between conceptual/intellectual merit and evidence. Broad-based surveys tend to define the major pathways/areas, while technology-focused reviews tend to outline the means and/or the emerging research that addresses them [1], [6]. For practical implementations, shared/common benchmarks, representative data sets, and implementable testbeds and interfaces are essential [5], [6]. This review aims to address this synthesis gap by identifying and describing main themes of the reviewed projects. The aim is not to state or imply that the projects analyzed represent all projects in the world, but rather to show what is actually represented in the reviewed projects.

The literature describes the likely evolution of wireless systems: a greater service categorisation, higher capacity, more connectivity, more reliable and low-latency communications, as well as more integrated computation and communication. A survey of the 6G frontier outlines the field through use cases, requirements, enabling technologies and research challenges, and serves as a useful reference to define the scope of the research interest [1].

While these vision and survey papers lay down a baseline, they are primarily agenda-setting. The papers aim to set research objectives and outline the capabilities of future networks, and vary in the extent of evidence of their implementation. The review regards 6G capabilities as research directions and reported design goals and objectives, rather than as assurances that all capabilities are commercialised and/or standardised.

METHODOLOGY

Research design

This study used the systematic review methodology to identify, assess and combine the evidence on AI networks and 6G. The adopted Waterfall model guided the organization and management of the review process as: requirements analysis defined focus of the review; system design mapped the review process with sources, search strings, instruments of appraisal and extraction; implementation retrieved records and removed duplicates; verification screened and assessed records, appraised study quality; reporting extracted and synthesized the evidence. PRISMA 2020 had a different purpose. It structured the review to openly report the process of identification, screening, eligibility and inclusion. Complementarity rather than substitution characterizes the two approaches. The stages of the Waterfall model represent the review process, and PRISMA 2020 defines the project management process.

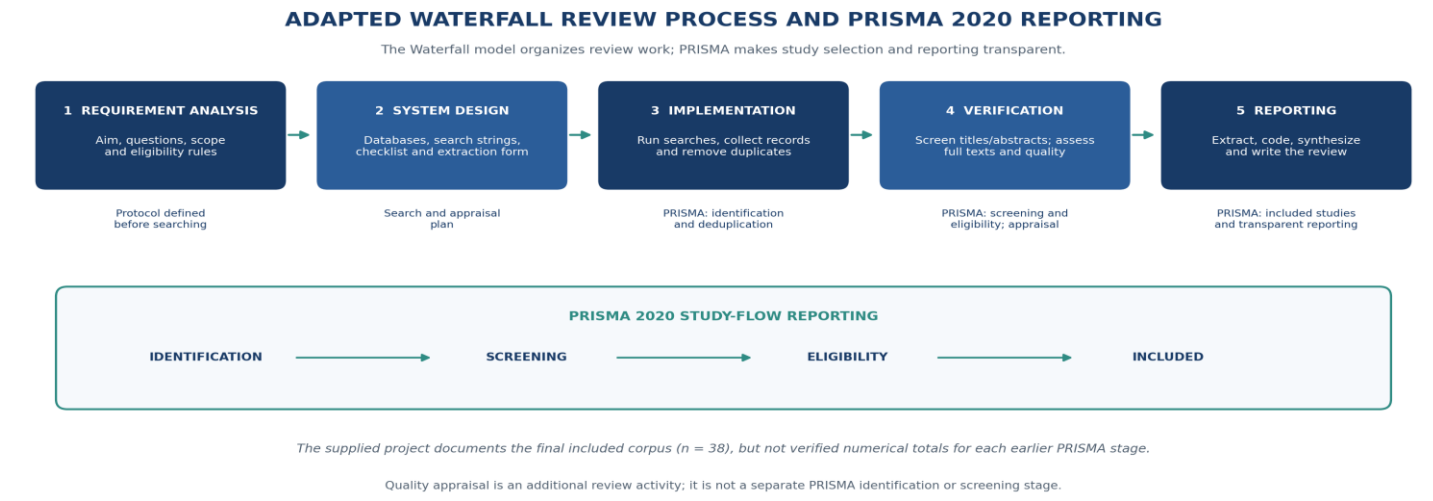

Figure 1. Relationship between the adapted Waterfall review process and PRISMA 2020 reporting.

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Table 1 shows where each step occurs in relation to reporting. Therefore, requirement analysis and system design precede study-flow reporting. Identification and deduplication are part of implementation. Verification encompasses screening and determination of eligibility, and includes quality appraisal. Reporting incorporates synthesis and includes a transparent presentation of the included evidence. The source diagram does not provide verified numerical totals for the individual PRISMA stages. Therefore, this manuscript reports the final corpus of 38 studies, and does not make any inferences regarding any missing stages.

Waterfall stage	**Application in this review**	**Relationship to PRISMA 2020**	**Documented output**
Requirement analysis	Define the aim, objectives, research questions, scope, and eligibility rules.	Pre-search protocol work; no direct PRISMA flow box.	Review focus and eligibility rules.
System design	Specify databases, Boolean queries, appraisal checklist, extraction form, and synthesis plan.	Protocol design before identification and screening are reported.	Search and appraisal protocol.
Implementation	Run searches, retrieve records, collate records, and remove duplicates.	Identification and deduplication.	Record set prepared for screening.
Verification	Screen titles and abstracts; retrieve and assess full texts; apply quality appraisal.	Screening and eligibility; quality appraisal is an additional review step.	Eligible and appraised studies.
Reporting	Extract data, code themes, synthesize findings, and prepare the manuscript.	Report included studies and the synthesis transparently.	Thematic synthesis and final report.

Data sources and search strategy

The review focused on English-language scholarly literature published from 2020 to 2025, consistent with the scope and study-level extraction matrix in the underlying project. The identified search resources included IEEE Xplore, ACM Digital Library, Elsevier ScienceDirect, SpringerLink, Scopus, Web of Science, Google Scholar, MDPI, Frontiers, Wiley Online Library, Taylor & Francis Online, and other scholarly publisher platforms. ITU and 3GPP documents were used for standards context; the principal evidence base remained scholarly literature. The project names these resources but does not provide a complete database-by-database search log, search dates, or individual database hit counts.

The search strategy combined AI and machine-learning terminology with 6G and enabling-technology terms using Boolean operators and exact phrases. The source protocol lists terms including artificial intelligence, machine learning, deep learning, reinforcement learning, deep reinforcement learning, federated learning, explainable AI, generative AI, AI-native networking, edge intelligence, and network intelligence; network terms included 6G, sixth generation, IMT-2030, beyond 5G, wireless and mobile networks, radio access, and core networks. Focused searches addressed semantic communication, edge and federated intelligence, RIS, THz, ISAC, network slicing, digital twins, security, privacy, trustworthy AI, generative AI, and large language models. Database syntax was adapted to the search fields available in each platform.

To respond to the recommendation to widen coverage, Table 2 lists supplementary search blocks for a future, documented rerun. These terms extend the themes already discussed in the project, particularly edge

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orchestration, and add zero-energy devices as a new search domain. The blocks are proposed search strings only: they were not run for this revision, and they do not add records to the current corpus.

Supplementary theme	Proposed search block (combine with 6G / IMT-2030 terms)
Semantic communication	("semantic communication" OR "goal-oriented communication" OR "task-oriented communication") AND (AI OR "machine learning" OR "deep learning")
Edge AI orchestration	("edge AI" OR "edge intelligence" OR "federated learning" OR "distributed learning") AND (orchestration OR placement OR scheduling OR coordination OR "resource allocation")
Zero-energy devices (new scope)	("zero-energy device*" OR "zero-power device*" OR "energy-harvesting device*" OR "ambient backscatter") AND (communication OR sensing OR network OR IoT)
Trustworthy AI and security	(security OR privacy OR explainability OR robustness OR adversarial OR poisoning) AND (network OR orchestration OR edge OR "model lifecycle")

Inclusion and exclusion criteria

Studies published between 2020 and 2025 and published in English were included, focused on AI networks, AI-enabled communication, AI-native networking or 6G. Included studies discussed at least one relevant AI-related technology or network function. The project excluded work published outside of the stated period, non-English publications, unrelated computing topics, unsupported opinions and marketing materials, records with unverifiable publication details and papers with only a peripheral relevance to the subject. The purpose of the study was to retain papers closely relevant to the research questions. The stated time frame of 2020-2025 reflects the source project's extraction matrix that includes 2020 studies and later publications.

Quality appraisal, extraction and synthesis

The studies were assessed using the project checklist to evaluate relevance, AI approach, 6G relevance, methodological clarity, evaluation, practical relevance, limitations and contributions. Study level extraction included author, year, theme, AI approach, 6G function, and reported gap or limitation. The wider protocol included extraction of bibliographic information, evidence type, findings, and evaluation approach. Research gaps were also captured. Literature was thematically synthesized into AI-native architecture and semantic communication; edge and federated intelligence; RIS, THz, ISAC, digital twins and network slicing; security and explainability; generative AI and sustainability. A statistical meta-analysis was not conducted due to heterogeneity in objectives, methods, datasets and metrics.

The project reports a final corpus of 38 studies and Appendix A provides study level extraction records. The source does not report verified numerical totals for all PRISMA intermediate stages and does not provide full text exclusion counts or database specific retrieval records. These gaps have not been bridged. The revised PRISMA figure shows the selection process and verified final count only. The qualitative judgments reported as quality ratings in Appendix B were reproduced and are thematic. The source notes that the extraction matrix can be enhanced by including information on the quality score, methodology, sample, type, and findings.

RESULTS AND DISCUSSION

Distributions of reviewed studies

Thirty-eight of the studies reviewed for this project were assigned a main theme. The distribution used for this project is presented in Table 3. The counts are for the selected review corpus and should not be construed to represent a census for 6G publications globally.

Dominant theme	Studies	Share
6G vision and architecture	8	21.1%
AI-native architecture and network automation	8	21.1%

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RIS, THz and ISAC	5	13.2%
Semantic and goal-oriented communication	4	10.5%
Digital twins and network slicing	4	10.5%
Security, privacy and trustworthy AI	4	10.5%
Edge and federated intelligence	3	7.9%
Generative AI and LLMs	2	5.3%

Table 3. Distribution of the 38 reviewed studies by dominant theme. Percentages are rounded and may not total exactly 100%.

The largest categories were 6G vision and architecture and AI-native architecture and network automation, with eight studies each (21.1% of the corpus each). Collectively, these two themes accounted for 42.2% of the corpus. Following these was RIS, THz, and ISAC (13.2%). Also in the corpus were semantic and goal-oriented communication (10.5%); digital twins and network slicing (10.5%); security, privacy and Trustworthy AI (10.5%); edge and federated intelligence (7.9%); and generative AI and large language models (5.3%). These distributions described the 38 studies in the sample only.

The distribution by year of publication below, is obtained from counting the 38 author-year entries in Appendix A, and gives a second descriptive view of the corpus. The nature of the sample remains purposive. Table 4. Distribution of extracted studies by year of publication (derived from Appendix A).

Table 4. Distribution of extracted studies by publication year (derived from Appendix A).

Publication year	**Studies**	**Share**
2020	8	21.1%
2021	7	18.4%
2022	6	15.8%
2023	6	15.8%
2024	5	13.2%
2025	6	15.8%
Total	38	100.0%

The counts in this report are for the 38 listed author-year entries in Appendix A, and total 38. Percentages are calculated against the total of 38 and rounded to the nearest digit.

Table 5 provides a structured technical comparison of the principal themes. The mapping is a qualitative synthesis of the study-level extraction matrix and the manuscript's thematic distribution. Where the underlying matrix reports a survey, proposal, architecture, or simulation rather than a validated deployment, the table preserves that evidence distinction.

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Table 5. Technical taxonomy and comparative feature mapping of the reviewed themes.

Theme (n; share)	AI / evidence approach in the source matrix	Primary 6G function represented	Reported benefit or contribution	Main limitation / evidence gap
6G vision and architecture (8; 21.1%)	Vision papers, conceptual analyses, and broad/technical surveys.	Defines 6G requirements, use cases, architecture directions, and enabling technologies.	Maps the expected 6G landscape and frames candidate capabilities.	Predominantly agenda-setting or conceptual; limited implementation and operator validation.
AI-native architecture and network automation (8; 21.1%)	AI architecture proposals, architecture/design studies, and AI-enabled network-management work.	Embeds learning, inference, automation, and control across network functions.	Supports integrated, adaptive network design and resource/network automation.	Few operator-validated implementations; monitoring, rollback, lifecycle governance, and testbed evidence remain limited.
RIS, THz and ISAC (5; 13.2%)	Technology surveys, principles/applications reviews, and deep-learning-aided intelligent-surface work.	Programmable radio propagation, high-frequency communication/sensing, and joint sensing-communication.	Provides physical and environmental enablers for intelligent 6G systems.	Hardware and propagation constraints, realistic channel models, training/overhead, and interface standardization.
Semantic and goal-oriented communication (4; 10.5%)	Deep-learning system model, position paper, and semantic-metric survey.	Transmits task-relevant meaning or intent rather than optimizing bit accuracy alone.	Can align communication with application goals and reduce irrelevant information transfer.	Task-dependent semantic value; common benchmarks, datasets, and success measures are immature.
Digital twins and network slicing (4; 10.5%)	Digital-twin surveys, network-slicing architecture/design, and applied AI slicing study.	Simulation, policy testing, monitoring, closed-loop management, and service-specific resource partitioning.	Can support planning, prediction, orchestration, and differentiated network services.	Model fidelity and delay, constructed datasets, dynamic demand, and limited deployment validation.
Security, privacy and trustworthy AI (4; 10.5%)	Security surveys and work on explainable, robust, or distributed-trust approaches.	Protects radio-edge-cloud functions, data, models, and automated network decisions.	Frames explainability, robustness, privacy, and security as native requirements.	Adversarial threats, model poisoning, privacy, auditability, and lifecycle assurance remain material gaps.
Edge and federated intelligence (3; 7.9%)	Edge-AI vision and federated-learning surveys.	Places inference/training near users and supports collaborative learning across data holders.	Can support latency-sensitive processing and privacy-aware distributed learning.	Data/model heterogeneity, straggler devices, communication overhead, model drift, and poisoning.
Generative AI and LLMs (2; 5.3%)	Comprehensive survey and review of GenAI / LLM integration.	Potential assistance for orchestration, automation, and troubleshooting.	Identifies emerging opportunities for network reasoning and operations support.	Reliability, privacy, accountability, and evidence for high-impact network decisions remain limited.

The qualitative ratings in Appendix B are reproduced in Table 6. They compare themes at group level: ‘High’ denotes strong relevance or elaboration, ‘Medium’ denotes a narrower or less validated/conceptual treatment, and ‘Emerging’ denotes a relatively new area with limited evidence in the reviewed material.

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Table 6. Group-level qualitative quality appraisal reproduced from Appendix B.

Study group	Relevance	AI detail	6G detail	Evaluation	Limitations	Overall use
6G vision papers	High	Medium	High	Medium	Medium	Core background
AI-native architecture papers	High	High	High	Medium	Medium	Core synthesis
Semantic communication papers	High	High	Medium	Medium	High	Emerging trend
Edge and FL papers	High	High	High	Medium	High	Core synthesis
RIS, THz and ISAC papers	High	Medium	High	Medium	High	Technology trend
Digital twin and slicing papers	High	High	High	Medium	Medium	Operational trend
Security and trust papers	High	Medium	High	Medium	High	Risk and governance
GenAI and LLM papers	High	High	Medium	Emerging	High	Recent direction

Integrated conceptual synthesis

The thematic synthesis indicates these trends are mutually dependent rather than isolated technology categories. Application and network drivers produce demand for AI methods. 6G enabler technologies comprise sensing, radio, edge and orchestration capabilities. These, in turn, serve network functions to improve the responsiveness and reliability of the services offered. Governance, security, privacy, explainability, energy, standards, and human oversight cover the full lifecycle of the end-to-end system.

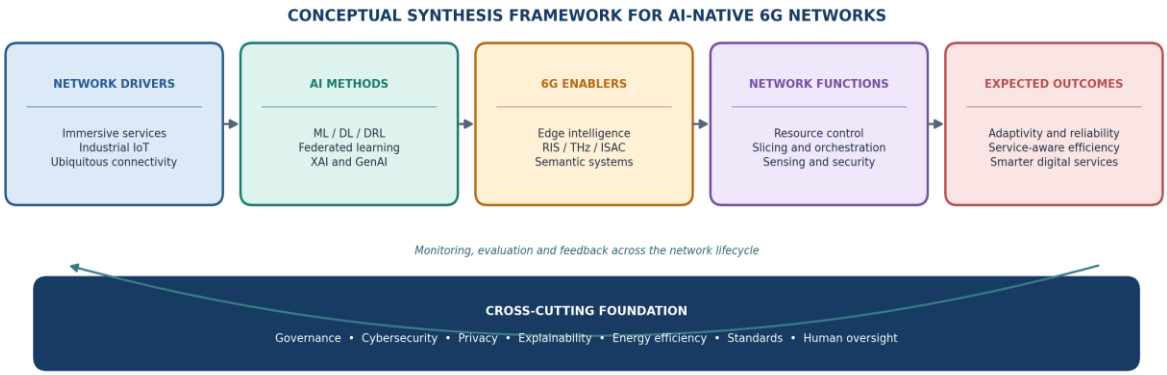

Figure 2. Conceptual synthesis framework for AI-native 6G networks.

Major Trends and Implications

AI-Native Architecture and Network Automation

The evidence suggests that AI is shifting from an add-on optimization tool to embedding intelligence throughout the data pipeline. The key advantage of this architecture is the flexibility to orchestrate and adapt to resources across the system. Some of the constraints are that a few high-level architecture frameworks exist, but few (if any) have undergone exhaustive monitoring and validation by operators.

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Edge Intelligence and Federated Learning

Edge intelligence moves learning and inference as close as possible to the end-devices. Federated learning enables collaboration among data holders without requiring them to share their raw data. Constraints for both solutions are Increased demand for communication and the need to work with heterogenous data including straggler devices and model drift. Attacks on the system such as model poisoning are also constraints. When evaluating these systems the cost, robustness and security should also be considered.

Semantic and Goal-Oriented Communication

Semantic and Goal-Oriented communication reduces redundant information by passing only information that is relevant to the goal. This may be efficient in some cases, but general communication performance is hard to measure due to lack of benchmarks and datasets. Future work should define the goal of the communication receiver and benchmarks to determine success.

RIS, THz and integrated sensing and communications

RIS, THz and integrated sensing and communications (ISAC) are positive trends. How quickly these technologies progress is limited by how quickly realistic hardware and channel models evolve. Implementing these technologies into production will require networking standards and compliance to legal and regulatory frameworks.

These will have the greatest effect when used with intelligent networking architectures.

Digital Twins and Network Slicing

Digital twins help networks with simulation, prediction, policy testing, and closed-loop management. These work hand in hand with network slicing, which helps use a shared network infrastructure to support different services with various requirements. Both require systems to effectively manage dynamic, unpredictable, and high demand conditions (e.g. reliability, security and energy). Model fidelity and latency have to be balanced based on the traffic and services supported.

Security, Privacy and Trustworthy AI

In the studies reviewed, security, privacy, and trustworthy AI, were the most cited concerns, at 23.7% of the studies. As radio, edge and cloud interconnects integrate sensing, digital twins and learning functions, attack surfaces increase. System designs must include explainability and adversarial robustness. Privacy and secure management of models throughout their lifecycle must also be addressed. Generative AI and large language models can help with orchestration and other advanced tasks, but accountability and reliability will constrain high-impact decisions.

Readiness Challenges

The second most cited challenges (21.1% of the total) were lack of real-world test beds and deployment validation. Other consistent challenges included: inadequate real world datasets, hardware and channel limits, gaps in standardization and interoperability, energy consumption, communication overhead, and the reliability of Generative AI.

Relatively more mature: Semantic communication is well represented in the corpus (4 studies, 10.5%) but falls into the ‘emerging’ category of the Source Quality matrix, thus representing a need for further metrics and evidence. Future work should target task-specific definitions, rather than generic claims of improved information transfer. [3] also recommends stating such benchmarks beforehand to avoid confusion with ‘conventional’ accuracy.

Edge AI Orchestration: Edge Intelligence and Federated Learning are represented by 3 studies (7.9%) in the thematic distribution. Other aspects of the wider extraction matrix connect AI-native Architecture, Digital Twins, and Network Slicing to Orchestration. The evidence discusses stragglers, communication overhead, model drift

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and poisoning as the primary operational concerns. A more holistic evaluation of orchestration should include a coordinated placement of inference and training activities along with radio/compute resource allocation and slice-level service requirements.

Policies can be tested with digital twins, and monitoring, explainability, and human oversight should govern the actions taken by the AI, with a rollback option available. The review does not settle on a best orchestration algorithm; various approaches should be benchmarked against transparent baselines to determine leadership.

Zero-energy devices: evidence boundary

Of the 38 studies in the review, and as documented in the Appendix A extraction matrix, zero-energy devices are not captured as a theme. The absence of zero-energy devices in the review is a gap in coverage to be tested by the additional search, and is not an indication that the technology is unimportant or mature. To include zero-energy devices in the review findings, the proposed additional search needs to retrieve studies where zero-energy devices are defined and deployed, and extraction should capture assumptions about device energy, communication and sensing functions, limits of the embedded computation, and any validating evidence. Until this work is done, the review findings do not include zero-energy devices.

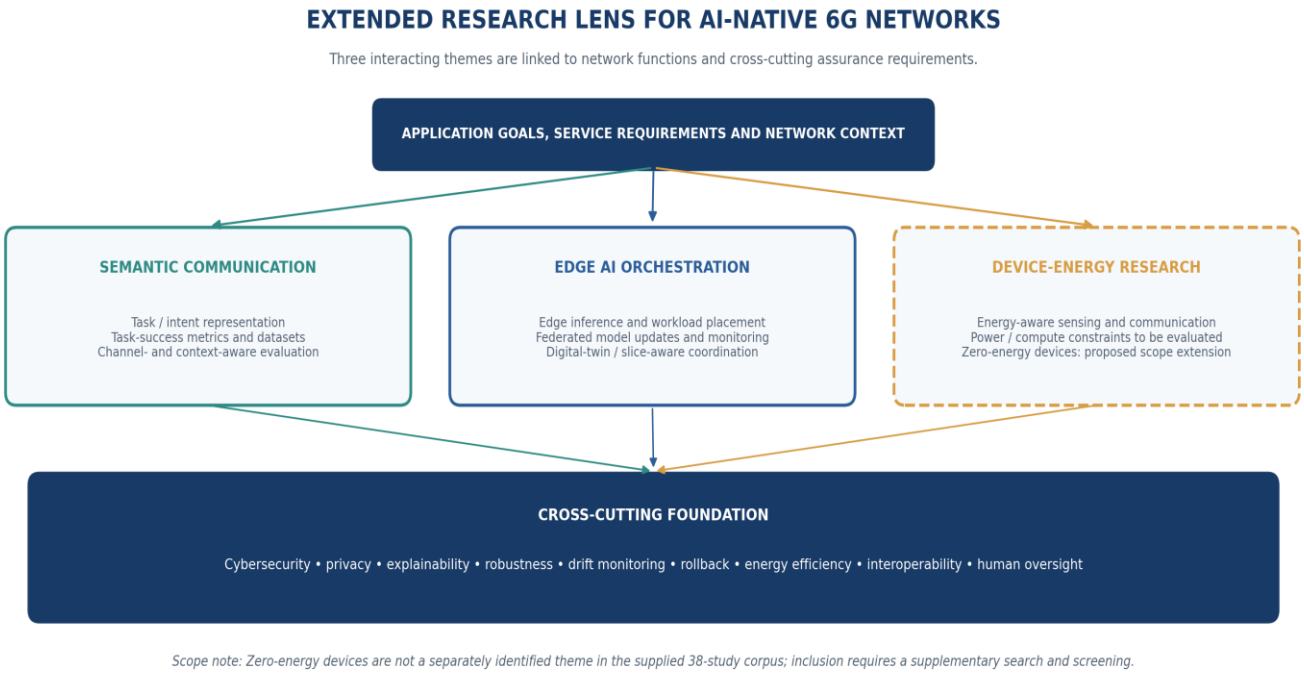

Figure 3. Extended research lens for semantic communication, edge AI orchestration, and device-energy research. The zero-energy-device element is a proposed scope extension, not a finding from the 38-study corpus.

CONCLUSION

This study reviewed AI and 6G literature between 2020 and 2025 and documented 38 studies in the accompanying project. The most mentioned topics included 6G vision and architecture and AI-native architecture, and network automation. The other topics included RIS, THz, ISAC, semantic communication, digital twins, network slicing, security and privacy, trustworthy AI, edge and federated Intelligence, and generative AI. Results from the comparative synthesis showed a representation of architectural concepts and a lack of deployment validation. Conversely, the source quality matrix noted semantic communication and GenAI/LLM applications as comparatively emerging areas.

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The available evidence noted an evolution from AI-assisted network optimization to AI-native design and integration across layers of the network for learning, inference, control and governance. It is important to note that the corpus is purposively selected and does not represent a census of all research. The review is also limited by the lack of publicly available, documented and detailed retrieval logs. This limited the verification of each step in the PRISMA framework. For these reasons, the final count of 38 was documented, but missing totals for each stage of mean PRISMA were not restored. Additionally, the project mentioned that the available research was primarily survey-proposal and experimental-based research and early testbeds, and not large-scale or commercial research.

Progress in this field will require more than adopting a new AI model. It will require reproducible datasets, realistic testbeds, task-specific metrics, energy awareness, explainability, privacy, cross-layer security, interoperable interfaces, and governance of the lifecycle. Translation of these requirements into a technical roadmap is shown in Table 7.

The roadmap represents research and validation prioritization. It does not mean that the proposed solutions have already been tested against the competition.

Actionable technical roadmap and future directions

The roadmap below shows the priorities based on the evidence reported in the project. The first goal should be to strengthen the evidence and document it. Thereafter, technological solutions should be assessed for security, privacy, and explainability over the lifecycle of the system, while using energy aware strategies.

study reviewed literature on AI and 6G networks from 2020 to 2025 using the 38 studies documented in the underlying project. The most represented areas were 6G vision and architecture and AI-native architecture and network automation. The remaining corpus addressed RIS, THz, ISAC, semantic communication, digital twins, network slicing, security, privacy, trustworthy AI, edge and federated intelligence, and generative AI. The comparative synthesis shows that architectural concepts are more extensively represented than deployment validation, while the source quality matrix identifies semantic communication and GenAI/LLM applications as comparatively emerging areas.

The evidence supports a movement from AI-assisted network optimization toward AI-native design in which learning, inference, control, and governance are integrated across network layers. However, the corpus is purposively selected and is not a census of all global research. The review is also constrained by the absence of complete database-specific retrieval logs and verified numerical counts at each PRISMA stage. Consequently, the final count of 38 is reported, but missing stage totals are not reconstructed. The project also notes that most evidence is drawn from surveys, proposals, simulations, experiments, and early testbeds rather than commercial deployment.

Future progress requires more than selecting a new AI model. It requires reproducible datasets, realistic testbeds, reliable task-specific metrics, energy-aware operation, explainability, privacy, cross-layer security, interoperable interfaces, and lifecycle governance. Table 7 translates these needs into a proposed technical roadmap. The roadmap is a set of research and validation priorities derived from the reported gaps; it does not imply that the proposed methods have already been tested or shown to outperform alternatives.

Table 7. Proposed research and validation roadmap derived from the identified gaps.

Priority area	Barrier identified in the review	Proposed technical / algorithmic work	Evidence required before claiming readiness
1. Search and evidence coverage	The selected corpus is 38 studies; detailed database-level logs and stage counts are not available.	Rerun the named scholarly sources with logged dates, exact query syntax, database-specific result counts, deduplication, full-text exclusion reasons, and consistent 2020-2025 or separately labelled updated-period	A reproducible search log, auditable screening decisions, verified PRISMA counts, and an updated extraction matrix.

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		criteria. Include the proposed semantic, edge-orchestration, and zero-energy query blocks.	
2. Reproducible datasets and testbeds	Limited real-world testbeds, deployment validation, and realistic datasets.	Create or curate documented benchmarks for slicing, mobility, semantic tasks, RIS control, edge intelligence, and security; specify baselines, evaluation conditions, data provenance, and reproducible experiment settings.	Independent reruns, realistic channel and workload conditions, and reported performance and resource costs.
3. Semantic communication	Task-dependent semantic value and a lack of common benchmarks and datasets.	Define the receiver task and task-success objective first; compare task-conditioned semantic encoding/decoding and learning-based communication against conventional baselines under stated channel and application conditions.	Shared datasets, explicit task metrics, repeatable comparison protocols, and clear limits on generalization.
4. Edge AI orchestration	Heterogeneous data/models, straggler devices, communication overhead, drift, poisoning, and uncertain operator validation.	Evaluate coordinated edge inference placement, federated update scheduling, and radio/compute/slice resource allocation. Compare rule-based or optimization baselines with reinforcement-learning / deep-reinforcement-learning candidates where justified; add drift detection, poisoning tests, explainability, monitoring, and rollback.	Measured latency, communication overhead, resource/energy use, robustness under heterogeneity and attacks, and safe fallback in a realistic testbed.
5. Zero-energy devices (new review scope)	This theme is not separately represented in the current 38-study extraction matrix.	First retrieve and screen eligible literature. If supported, compare reported energy assumptions and test energy-aware sensing, transmission, and computation scheduling under the device constraints described by the retrieved studies.	A screened evidence set and study-specific validation data; no readiness claim until eligible studies and measurements are documented.
6. Trustworthy AI and cross-layer security	Privacy, adversarial robustness, model poisoning, explainability, and accountability across radio, edge, and cloud.	Integrate secure model/data lifecycle controls, privacy-aware learning, adversarial and poisoning evaluation, explainable decisions, access controls, human approval for high-impact actions, and tested rollback procedures.	Threat-model coverage, security and privacy tests, audit trails, explanation quality, recovery tests, and operator review.
7. Interoperability and operational governance	Standardization gaps, multi-vendor integration, energy use, reliability, and cost of integration.	Test standard-aligned interfaces across integrated multi-vendor components; document model/version management, service-level constraints, energy use, OPEX/CAPEX integration assumptions, accountability, and human oversight.	Multi-vendor testbed results, interface conformance, lifecycle records, operational cost evidence, and transparent maturity statements.

Evidence boundary. The revised manuscript retains the 38-study corpus and the 12 references already present in the journal article. The supplementary search blocks, orchestration algorithms, and zero-energy-device work are proposed future research activities; they are not represented as completed database searches, included studies, or validated findings.

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