From Packets to Tasks: Rethinking 6G for Robotics

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***Abstract*—Large-scale, safety-critical, and autonomous robotic systems are emerging as demanding 6G use-cases that expose the limits of connectivity-centric network design. While 5G introduced relevant capabilities such as ultra-reliable low-latency communication (uRLLC), integration with time-sensitive networking (TSN), private networks, network slicing, positioning, and edge computing, next-generation robotic deployments require task-level assurance, closed-loop coordination, and outcome-oriented service delivery. This *(short)* paper argues that robotics can help redefine 6G by shifting the design focus from packet- and flow-level quality-of-service toward task completion, deadline compliance, safety assurance, and operational value. We classify robotic systems according to where 5G is sufficient, strained, or inadequate, identify key 5G gaps, and discuss the implications of physical and embodied AI for future network design. A simulation-based techno-economic evaluation shows that task-centric 6G improves robotic service quality and enables clearer monetization through outcome-based models. These findings motivate task and business KPIs as essential metrics for evaluating 6G-enabled robotics.**

***Index Terms*—5G, 6G, AI, business model, connectivity, robotics, task-oriented communication.**

I. Introduction

Mobile networks have historically been designed and evaluated using connectivity-centric key performance indicators (KPIs), such as throughput, latency, reliability, coverage, availability, and connection density. These metrics are essential for engineering and operating large-scale communication systems. However, they do not always capture whether a cyber-physical application has achieved its intended goal. This gap becomes particularly visible in robotics, where network behavior can directly influence perception, planning, actuation, safety, and task completion. The transition from 5G to 6G therefore raises a fundamental question: *should future networks continue to optimize packet delivery, or should they also provide assurance for real-world outcomes*? For robotic systems, the relevant question is not only whether a packet arrived within a target delay bound, but whether a robot or robot fleet completed its task safely, efficiently, and predictably. This implies a shift from QoS for packets to QoS for tasks.

5G already introduced important capabilities for industrial and robotic applications. Ultra-reliable, low-latency communication (URLLC) aims to support low-latency and high-reliability services, time-sensitive networking (TSN) integration targets deterministic industrial networking, private 5G provides enterprise control, positioning improves localization support, edge computing brings computation closer to devices, and exposure APIs create pathways for applications to interact with network capabilities. Yet, many industrial deployments remain bespoke, integration-heavy, and difficult to scale across vendors and sites. The challenge is not the absence of individual features, but their lack of integrated, end-to-end, task-aware assurance.

This (*short*) paper examines how robotics can shape 6G design, evaluation, and commercialization. It characterizes 6G and robotics as symbiotic, distinguishes robotic systems that can rely on advanced 5G from those that are stronger 6G drivers, and identifies the limits of current 5G/edge deployments for end-to-end task assurance. It further examines the implications of emerging AI paradigms, particularly physical and embodied AI, for network design. Finally, it discusses outcome-oriented monetization and presents an illustrative simulation-based techno-economic comparison of connectivity-centric and task-centric multi-robot services.

A. Related Work

Recent work increasingly treats robotics as a key 6G vertical. Ghassemian *et al.* mapped IMT-2030 capabilities to robotic functions and proposed integrated robotic, intelligence, and network-service planes [1], while Vukobratovi'c *et al.* introduced a unified sensing, computing, communication, and control fabric for demanding applications [2]. Specific enablers are also being explored: Priyanta *et al.* developed an integrated sensing and communication (ISAC)-based cooperative perception framework [3]; task-oriented and AI-native mechanisms support tighter network–robot coupling [4]; Li and Aijaz combined semantic communication with a generative-AI agent for multi-robot coordination [5]; and Li *et al.* further studied generative AI in the loop for joint adaptation of connectivity and robotic operation [6]. Trustworthiness and ethical alignment are addressed in [7].

Despite this progress, the literature remains split between broad visions and studies of individual enablers. It does not clearly identify which robotic systems genuinely require 6G, where advanced 5G may suffice, or how packet-level performance translates into task completion at scale. This paper addresses these gaps through a robotics classification and highlights the symbiotic relationship between 6G and robotics, whereby each both enables and shapes the other.

II. 6G and Robotics

The relationship between 6G and robotics is symbiotic. 6G can provide the deterministic communication, sensing, computing, and programmability needed for autonomous robotic systems at scale, while robotics offers a demanding real-world environment that can shape what 6G must become. This co-evolution extends beyond higher data rates to encompass closed-loop control, precise positioning, integrated sensing, dynamic compute placement, exposure APIs, and end-to-end operational assurance.

A. 6G for Robotics

Robotic systems are evolving from isolated automation to distributed autonomy, spanning warehouse robots, cobots, hospital robots, autonomous ports, drone swarms, and city-scale platforms. Beyond connectivity, they require coordinated sensing, shared awareness, and dependable control loops.

6G can support robotics through four key capabilities. First, the envisaged hyper-reliable and low-latency connectivity can reduce uncertainty in perception-to-action pipelines. Second, high-precision positioning and integrated sensing can complement onboard sensing and support safety zones, navigation, and cooperative localization. Third, edge AI processing can offload computation from resource-constrained robots and enable shared intelligence across fleets. Fourth, programmable exposure interfaces can allow robotic applications to express service intent, monitor assurance, and adapt behavior according to network and compute conditions.

The objective is not simply to connect more robots. It is to enable robotic systems that operate safely and predictably even under mobility, congestion, interference, and changing task priorities. In this sense, 6G must deliver QoS for what matters in the real world: *the successful execution of robotic tasks*.

B. Robotics for 6G

Robotics also forces 6G to confront requirements that are difficult to capture using traditional mobile broadband assumptions. In mobile broadband, a temporary reduction in throughput may degrade user experience but often does not create immediate physical consequences. In robotics, a delay spike, localization error, or missed coordination message can affect motion, safety, and productivity.

This changes several design assumptions. Reliability must move beyond statistical packet delivery toward task-level reliability. Latency must be considered not only as an average or percentile measure, but also as a bounded and predictable property under load. Traffic cannot be treated as generic data; it has task context, priority, and semantic value. Finally, the network can no longer remain a passive data pipe. It must participate in closed-loop orchestration across robots, edge platforms, and applications.

Robotics therefore becomes a stress test for 6G. It exposes limitations in multi-domain coordination, end-to-end assurance, and interoperability. It also motivates new capabilities such as task-aware scheduling, semantic communication, intent-based service management, network digital twins, and AI-native control loops.

III. Is 6G Required?

It is important not to overstate the need for 6G. Many robotic systems can operate effectively with wired networks, Wi-Fi, 4G, or 5G depending on their requirements. The need for 6G emerges from scale, safety, autonomy, and coordination rather than from robotics in general.

Table I provides a requirements-centric classification. Structured and isolated robots, such as fixed industrial arms or CNC automation cells, usually operate in deterministic environments with limited mobility. These systems may require connectivity for monitoring and control, but 5G is often sufficient. Connected mobile robots such as AMRs and AGVs introduce mobility and local coordination; they can often be served by enhanced 5G and edge coordination. Collaborative and safety-critical robotics, including hospital robots, cobots, and remote maintenance systems, strain current systems because predictable latency, high reliability, and accurate positioning become safety-relevant. Finally, large-scale autonomous multi-agent systems, including drone swarms, autonomous ports, and city-scale robotics, require deterministic closed-loop control, synchronized sensing, distributed intelligence, and task-aware networking. These systems are where 5G is most likely to become insufficient.

This classification suggests that 6G should not be justified by simple connectivity use-cases. Instead, 6G should target robotic scenarios where the network becomes part of the operational control system. These scenarios require guarantees that are difficult to provide through isolated radio features alone.

IV. Where 5G Falls Short for Robotics?

The key issue with 5G for robotics is not that it lacks relevant features. Rather, 5G capabilities are often fragmented across domains and are not yet mature enough to provide end-to-end task assurance. Robotics requires the alignment of radio, transport, edge computing, application logic, safety policies, and operational monitoring. Current deployments frequently require use-case-specific engineering to achieve this alignment.

URLLC improves low-latency and high-reliability communication, but robotic tasks require assurance across the full chain from sensing and communication to computation, control, and actuation. Radio-layer reliability alone does not guarantee task success. TSN integration is promising for industrial convergence, but end-to-end 5G–TSN integration remains complex in multi-vendor deployments and requires careful validation across layers. Private 5G gives enterprises more control, but deployment remains engineering-heavy when specific latency, availability, and determinism targets must be achieved.

Edge computing reduces the distance between intelligence and devices, but local computation alone is insufficient. Robotics requires deterministic coordination among the robot, network, edge, and application. Network slicing can isolate resources, but robotic tasks need dynamic, fine-grained adaptation across compute, radio, and application states. Positioning is valuable for mobile robots and safety zones, but its value depends on being robustly coupled with control, safety, and context awareness. Finally, exposure APIs are essential because robotic applications need to express intent and monitor

TABLE I
ROBOTICS CLASSES AND INDICATIVE NETWORK REQUIREMENTS.

Class	Examples	Network requirement	Assessment
Structured / isolated	Robot arms, CNC cells	Connectivity, monitoring, moderate latency	5G sufficient
Connected mobile	AMRs, AGVs, logistics robots	Reliable mobility, bounded-area coordination, local edge support	5G+
Collaborative/safety-critical	Cobots, hospital robots, remote maintenance	Predictable latency, high reliability, positioning, safety support	5G strained
Large-scale autonomous multi-agent	Drone swarms, autonomous ports, city-scale robots	Deterministic closed-loop control, synchronized sensing, distributed intelligence, task-aware networking	6G driver

service quality; without stronger APIs, the network remains insufficiently application-aware.

A key gap is the mismatch between network KPIs and robotic KPIs. Operators may report latency, throughput, and availability, while robotic users care about task completion rate, time-to-service, mean time to assure, energy per task, safety-zone assurance, and fleet productivity. Bridging this gap requires task-level abstraction and cross-domain observability.

This motivates the concept of task-oriented 6G. In such a system, network assurance is not limited to packets or flows. It is linked to the robotic task being executed, the safety context, the operational environment, and the required control loop. The network must be able to expose capabilities, receive intent, allocate resources, and adapt policies in real time.

V. 6G AND AI PARADIGMS

The evolution of AI paradigms further reinforces the need for task-oriented 6G. A useful distinction can be made between physical AI and embodied AI. In one (*telco-centric*) interpretation, *physical AI* refers to the intelligence embedded in infrastructure, devices, and systems that sense, connect, compute, and automate physical-world processes. This can be understood as building a nervous system for cyber-physical environments. Networks that support physical AI must provide connectivity, sensing, compute, synchronization, and automation. *Embodied AI* goes further by emphasizing intelligence that learns through interaction with the environment. An embodied robotic agent does not merely process data; it perceives, acts, receives feedback, and adapts. This creates a continuous perception–planning–action–learning loop. In this paradigm, the network is not simply a transport substrate. It can become part of the intelligence loop by supporting shared perception, distributed reasoning, cooperative learning, and adaptive control.

The implication for 6G is significant. Networks must evolve from connectivity infrastructure toward closed-loop intelligence infrastructure. This requires AI-native orchestration across device, edge, cloud, and network domains. It also requires trust, explainability, and safety mechanisms because AI-driven network decisions may influence physical actions. The most promising capability in this context is intent-aware AI-native edge–cloud orchestration. Such orchestration would decide dynamically what runs on the robot, what runs at the edge, what goes to the cloud, and what level of latency, reliability, positioning, and sensing support the task requires.

Several mechanisms can contribute to this vision. Semantic and goal-oriented communication can reduce communication load by prioritizing task-relevant information. ISAC can provide environmental awareness in addition to data transport. Network digital twins can test policies before deployment in live environments. Intent-based interfaces can simplify service onboarding by allowing applications to specify desired outcomes rather than low-level network parameters. The challenge is to integrate these mechanisms into deployable, interoperable systems.

VI. THE MONETIZATION CHALLENGE FOR 6G

A major lesson from 5G is that better connectivity does not automatically translate into better monetization. Many advanced 5G features have been difficult to monetize at scale because enterprises do not purchase radio features in isolation. They purchase productivity, reliability, safety, and operational efficiency. Robotics makes this distinction explicit.

Traditional network-centric KPIs include throughput, latency, reliability, coverage, availability, and connection density. These are necessary for network engineering, but they do not directly express enterprise value. In robotic deployments, the monetizable value may be task completion rate, time-to-service, mean time to assure, energy per task, safety-zone assurance, or fleet productivity. This creates an opportunity for 6G to shift from selling connectivity to delivering outcomes.

Several business models could emerge. Mission-critical connectivity could be sold with task-level SLAs rather than generic network SLAs. Network, edge, AI, and sensing capabilities could be bundled as an outcome-enabling platform. Exposure APIs could support a capability economy in which applications request assured positioning, safety-zone support, or control-loop reliability. Robotics-as-a-Service providers could integrate network assurance into their offerings. Operators could move from charging for data volume or connectivity access toward charging for assured operational performance.

However, this opportunity depends on solving the technical foundations. Outcome-based monetization requires standardized APIs, shared KPI definitions, interoperable platforms, and trustworthy assurance mechanisms. Without these foundations, robotics may remain trapped in pilots and bespoke

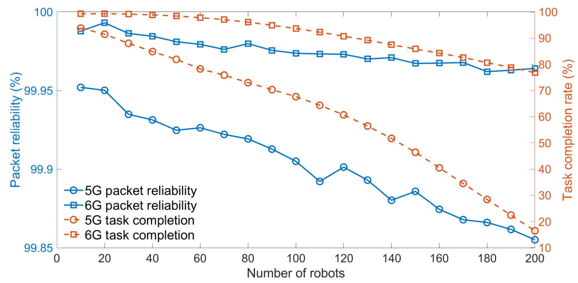

Fig. 1. Packet reliability and task completion versus robot fleet size.

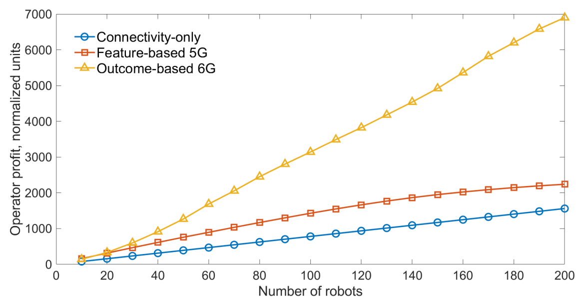

Fig. 2. Operator profit versus under different monetization models.

deployments, repeating some of the monetization difficulties experienced in 5G.

VII. Techno-Economic Assessment

We conduct an illustrative system-level evaluation comparing a connectivity-centric 5G/edge baseline with a task-centric 6G design under the same multi-robot workload. The fleet size varies up to 200 robots and includes representative monitoring, transport, safety-critical, and perception-offloading tasks. Communication and processing conditions become more demanding as the fleet grows, reflecting increased congestion, mobility, and competition for edge resources. Results are averaged over multiple randomized simulation runs.

The 5G baseline prioritizes reliable connectivity and conventional QoS differentiation, whereas the 6G design introduces task awareness and tighter coordination across communication, edge computing, and robotic operation. A task is considered successful only when its communication and control requirements are satisfied. We compare the two designs using packet reliability and task-completion rate, and assess connectivity-only, feature-based, and outcome-based pricing through operator profit. The evaluation is intended to compare service-design principles rather than reproduce complete standardized 5G and 6G protocol stacks.

Figure 1 highlights the mismatch between packet-level and task-level performance. Across the evaluated range, packet reliability remains above approximately 99.85% for both designs. Nevertheless, when the fleet size increases from 10 to 200 robots, the task-completion rate of the connectivity-centric 5G baseline falls from about 94% to 17%. In comparison, the task-centric 6G design maintains a completion rate of approximately 77% at 200 robots. These results corroborate the earlier discussion that reliable packet delivery alone does not ensure robotic service quality, which also depends on deadline compliance, control-loop stability, and coordinated communication and edge processing.

Figure 2 shows the corresponding monetization trends. At 200 robots, the connectivity-only and feature-based 5G models achieve profits of approximately 1,560 and 2,240 normalized units, respectively, whereas the outcome-based 6G model reaches about 6,920 units. Thus, the outcome-based model provides roughly 4.4 times the profit of connectivity-only pricing and about three times that of feature-based pricing in the densest scenario. Although the monetary values are normalized, the results support the proposition that robotics offers a stronger monetization opportunity when operator revenue is linked to assured task outcomes rather than connectivity or isolated network features.

VIII. Concluding Remarks

This paper argued that robotics can help redefine 6G by shifting network design from packet delivery toward assured task outcomes. Although advanced 5G provides useful foundations, large-scale, safety-critical, adaptive, and multi-agent robotics expose persistent gaps in end-to-end assurance, task awareness, and cross-domain coordination. These systems require deterministic operation, synchronized sensing, AI-native orchestration, and programmable network exposure. Embodied AI further reinforces the need for networks to participate in closed-loop intelligence rather than act solely as data pipes.

The illustrative evaluation showed that high packet reliability does not necessarily translate into successful robotic task execution, while task-centric design sustains better performance as fleet density increases. It also indicated the potential value of outcome-based monetization over connectivity-only and feature-based models. As this work is ongoing, future research will validate these findings through testbed-based experiments, refining the techno-economic model using deployment-grounded assumptions, and evaluating feature-based 6G service offerings alongside task- and outcome-oriented models.

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