

COMPUTER AND CONTROL ENGINEERING

DAUIN - Goal-Oriented Adaptive Learning for 6G

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Context of the research activity	<p>6G will connect autonomous systems, requiring a shift from traditional data delivery to goal-oriented communication. This AI-driven approach prioritizes relevant data for decision-making, optimizing efficiency. Key areas include intelligent routing, semantic exchange, and intent-based models. This PhD research aims to develop AI-orchestrated data exchange, explore causal inference and contrastive learning for relevance extraction, and design adaptive, task-driven networking frameworks.</p>
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	<p>Traditional communication paradigms, which emphasize reliable data delivery regardless of its relevance, will become inefficient in future 6G environments where real-time decision-making, task execution, and AI-driven automation are the primary objectives. Goal-oriented communication shifts the focus from delivering raw data to exchanging only the information necessary to achieve a specific task or objective. This means that rather than transmitting redundant, irrelevant, or low-priority data, networks will use AI-native decision-making mechanisms to determine what data is necessary, when it should be transmitted, and how it should be optimized for efficiency.</p> <p>Goal-oriented communication can transform networking into an intelligent, context-aware, and task-driven system by focusing on:</p> <ul style="list-style-type: none"> - Intelligent Routing and Data Prioritization: Instead of treating all packets equally, goal-oriented communication prioritizes and routes information based on its relevance to an ongoing process. For example, in an autonomous traffic management system, real-time hazard notifications should take precedence over general telemetry data. - Semantic and Task-Aware Information Exchange: Networks will no longer transmit all available data but instead extract and share only the information necessary for AI models or human users to make a decision. For example, in industrial automation, rather than sending thousands of sensor readings per second, a machine could communicate only when an anomaly is detected, significantly reducing bandwidth and computation costs. - Intent-Based and Goal-Driven Communication Models: Goal-oriented networks move beyond conventional request-response models to intention-based data exchange, where AI-driven entities anticipate what information is
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Objectives

needed to complete a task and optimize communication accordingly. For instance, in autonomous vehicle coordination, a vehicle does not need to continuously broadcast its speed and position but only shares critical updates when approaching intersections or hazards.

The main objectives of this PhD research are:

- Define AI-Orchestrated Data Exchange Models, by developing AI-driven approaches to filter, prioritize, and exchange only task-relevant information between connected devices and infrastructures. The PhD candidate will be required to investigate techniques such as semantic communication, federated meta-learning for adaptive network intelligence, and goal-oriented routing to optimize network resource utilization.

- Investigate innovative AI techniques to be used with goal-oriented communication, such as Dynamic Causal Inference for Relevance Extraction (models that leverage causal reasoning to identify the true cause-effect relationships within network data, thus enabling the system to determine which pieces of information are causally relevant to a given goal, rather than merely correlational) or Multi-Modal Contrastive Learning for Unified Semantic Representation (using contrastive self-supervised learning to fuse data from multiple modalities, e.g., sensor data, localization information, communication signals, into a cohesive semantic representation that emphasizes task-specific features.)

- Develop Context-Aware and Task-Driven Networking Frameworks, by designing adaptive, scalable and goal-oriented communication models that dynamically adjust information exchange based on real-time context and application needs.

Implement AI-based decision-making frameworks to ensure that communication serves system-wide objectives rather than individual data requests.

Skills and competencies for the development of the activity

The ideal candidate should have a strong understanding of networks and advanced communication technologies, including RAN, 5G, and 6G systems. They should be proficient in protocol design and optimization and have a grasp of methodologies for the integration of AI-driven solutions in next-gen networking. Proficiency in programming (Python, TensorFlow/PyTorch) and network simulation tools is required. Analytical skills, and experience with predictive modelling and analysis are highly valued.