COMPUTER AND CONTROL ENGINEERING

CNR/IEIIT - Advanced communication technologies for automation

Funded By	C.N.R. - CONSIGLIO NAZIONALE DELLE RICERCHE [P.iva/CF:02118311006]
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Context of the research activity	Industry 4.0/5.0 and the Industrial Internet of Things are the main drivers that will shape the evolution of communication for automation. Similar requirements are found in other application fields, like multimedia streaming, online user interaction, and environmental sensing. Broad-scope research activities, not rigidly tied to any specific communication technologies, are the key for devising holistic solutions able to meet application constraints in modern heterogeneous scenarios, and are at the core of this proposal.
	Unlike the past decades, where the primary goal of transmission technologies was typically bare speed, next-generation industrial, office, and home networks will likely consist of a potentially large number of connected nodes (up to a few hundred in some cases), whose interactions must satisfy a variety of requirements that can be expressed by suitable key performance indicators (KPIs), e.g., latency, jitter, reliability, availability, and power consumption. Properly supporting communication among entities in distributed applications, in such a way that their constraints, specified through said KPIs, are always met (or, at least, in the vast majority of cases) could be a real challenge, especially when wireless transmissions are involved. As a matter of fact, any specific wireless technology is likely unable to satisfy alone all requirements, and this is particularly true for those solutions which operate on a single communication channel. Consequently, future communication systems will include a plurality of coexisting wireless networks characterized by different capabilities, features, and cost. For example, IEEE 802.11 (Wi-Fi 6/7/8) is targeted at high throughput and low latency on local areas, IEEE 802.15.4 can be exploited by multi-hop ultra-low power wireless sensor (and actuator) networks (WSN/WSAN), 5G/6G enable high throughput and low latency over wide (geographic) areas, LoRa/LoRaWAN support long-range low-power data transmission, Bluetooth Low Energy (BLE) suits small-range ultra-low power connections, and so on. In heterogeneous contexts, issues like, e.g., mutual interference, either within the same network or between different technologies, and the mobility of

Objectives	nodes, pose significant challenges, which make it difficult to comply with the required KPIs. A point to be carefully considered is how the different networks should be interconnected so that KPIs could be ensured to end-to-end communication. This aspect is particularly relevant when communication paths include both wired and wireless segments, as happens in the real world. For the wired ones, Time-Sensitive Networking (TSN) is expected to become the standard solution for satisfying the needs of time-aware applications. However, when mobility is involved, paths are partially wireless, and constraints (about, e.g., latency and reliability) have to be met on air as well. Defining harmonized strategies to achieve these goals is one of the main challenges about communication for automation in the next future. In particular, this research proposal seeks the definition of intelligent networks, which exploit advanced access mechanisms, scheduling/reservation techniques, and possibly algorithms based on artificial intelligence and machine learning to react proactively to any changes in the surrounding environment, either to improve one or more KPIs or, al least, to preserve a certain quality of service in spite of adverse conditions. As a possible research plan, after the selection of one or more relevant wireless communication technologies among those listed above, the Ph.D. candidate must investigate (and possibly propose) some improvements, assessing at the same time how KPIs are affected. As said before, the research activities will be possibly extended to include selected wired technologies (e.g., TSN), which share many aspects with their wireless counterparts. For example, the use of cross-technology redundancy techniques may be envisaged where the MAC layer of the wireless segments of the network is enhanced in such a way to foresee the automatic selection of the best transmission channel, transmission rate, and even transmission technology. To this purpose, machine learning (ML) and/or reinforcement learning (RL) could be exploited. All the proposed techniques will be validated through simulation, mathematical models, and/or by implementing demonstrators. To ensure flexibility, no specific constraints are given at this stage for the workplan. Instead, three basic aspects are defined for the research activities to be performed: 1) Application scenario: distributed automation systems are chosen because they are quite demanding and pose significant challenges, as defined by a well-defined and agreed set of KPIs. Extensions to similar contexts, like multimedia streaming and online interaction, is possible if deemed relevant. 2) Communication infrastructure: heterogeneous networks are considered that potentially include both wireless and wired parts. For the former, several different technologies that do not require any subscriptions will be analyzed. Extensions to 5G/6G is possible if deemed relevant. 3) As far as possible, both single technologies and holistic solutions will be studied (the latter are often left out in the specialized literature). Improvements on KPIs will be also assessed on end-to-end communication. Possible venues for publications are: - all the Conferences and Journals of the Industrial Electronic Society of the IEEE, e.g., IEEE Transactions on Industrial Informatics, IEEE Open Journal of the Industrial Electronics Society, IEEE Transactions on Industrial Cyber-Physical Systems, etc. - other IEEE journals, e.g., IEEE Transactions on Wireless Communications, IEEE Internet of Things Journal, etc.

	- broader-spectrum Journals like IEEE Access - Journals from other Publishers like Ad Hoc Networks and Computers in Industry (Elsevier) - more in general, all the Journals or Conferences about communication for automation. The Ph.D. student will be involved in the activities of PNRR Projects carried out by partner CNR-IEIIT, for which a Research Scholarship in going to be granted. The related activities are completely aligned with those described in the above workplan.

Skills and competencies for the development of the activity	The Ph.D. candidate must possess a high-profile, preferably with an outstanding school record (MS degree and exams' marks), proven autonomy, and the ability to think out-of-the box. A detailed knowledge of the Python language is required, as well as some skills about formal languages and translators. Prior experience about industrial applications and their implementation is appreciated. Basic knowledge of wireless and wired communication systems is also required.