WHITE PAPER AP2
FUTURE INTERNET

Executive summary

Future Internet activities have a number of innovative and impacting trends in industries and society and are influencing topics such as knowledge distillation from big data, social networking, secure systems, digital industry. Many recent and emerging paradigms are related to our activities, to mention a few Cyber Physical Systems (CPS), Internet of Things (IoT), Internet of People (IoP). Further information may be found in vision documents and strategic agenda such as Artemis-IA, HiPEAC , EPoSS and others.

Looking at the national and international context in the next 5-10 years, it is possible to cluster our activities in three themes, i.e., **Next Generation Internet (NGI)**, **Distributed Parallel and High Performance Computing (HPC)**, and **Software Engineering (SW)**. The NGI theme covers communications, network monitoring, novel Internet paradigms, and IoT technologies, with a special emphasis on Industrial Internet (Industry 4.0). HPC deals with cloud, edge computing and high-performance computing. SW covers all typical aspects of software engineering, including formal methods, software monitoring, testing and verification, programming paradigms such as agent-based models.

We are perfectly aligned with the Future Internet strategic research directions, at the national and **international levels**. With respect to FP9 [FP9], two of the three themes (NGI and HPC) are “Areas of Intervention” for the “Digital and Industry” cluster under the “Global Challenges and Industrial Competitiveness” pillar. SW will not be a specific Area of Intervention, but it is indicated in many others (e.g., “Digital Technologies” and NGI), as a key enabling theme. All activities are relevant also in the other FP9 pillars, i.e., “Frontier” (covering infrastructures and ERC), and “Open Innovation”. The three themes are present in the research agendas of the main non EU funding agencies. For example, they are subject of NSF solicitations in the Computer Systems Research (CSR) [CNS17] and the Cyber-Human Systems (CHS) [IIS17] areas.

This characterization also maps into the latest Italian PNR program [PNR15]. The three themes are relevant for the five “bacini di domanda” and the 12 “aree di specializzazione”. Results from the DIITET activities are applicable to all the four considered technological groups: “Prioritarie” (Fabbrica Intelligente), “In Transizione – Emergenti” (Smart Communities, Tecnologie per ambienti di vita), “Ad alto potenziale” (Made in Italy), “Consolidate” (Mobilità).

1 State of the art

1.1 Theme: Next Generation Internet

NGI encompasses the FP9 areas [FP9] of Future Internet communication and networking. The SoA can be described for key lines in the NGI research agenda.

NGI communication technologies beyond 5G and network measurements

Communication systems have a range of applications, i.e., health-care, smart-living, manufacturing. New microcontroller and radio technologies have also enabled new products. Considering the exponential number of radio devices [VF14], wireless networks are dense, calling for self-organized and cognitive architectures [SSSB08].

Mobility aspects (*mobile Internet*) at different scales, from pedestrian to vehicular, are key. With vehicles autonomously communicating, mobile technologies become critical to support novel services [EU17]. *Satellites and UAVs* (Unmanned Aerial Vehicles) are part of the (beyond-)5G technologies, complementing global coverage of terrestrial communications.

Finally, measurements techniques characterise the current Internet and NGI. New methodologies for *large-scale* NGI topological maps are required.

NGI network paradigms

NGI is *human-centric* [FP9]: users are immersed in personal mobile devices and “things” generating data. Personal devices become “proxies” of their users and adopt models of the human behavior to organize the network and filter data. This vision is a root of NGI [FP9], and already generated a research community [CDP17,L18,Q16,B17].

NGI is also a *Information-centric* (or data-centric) [XVS16]. ICN is expanding from the Internet core to the edges, supporting mobile networks and IoT [ACQ16, BMH14], even though solutions are not yet well suited for them [LAS16, ACM14, GAM14, WK16, BCO14].

Another area is the integration between *networking and computation* (see Section 2.2).

IoT and WSN in NGI and NGI industrial networks

IoT and wireless sensor networks (WSN) are key in many applications, e.g., smart city, smart industry, smart maritime environments. Issues are energy management, QoS, security, data collection, limited resources, robustness. *Interoperability* is a main pillars [WMRD11], addressing reusable designs for composition of services [DLD16, D18].

In the *industrial* domain, Industry 4.0 and PNI4.0 [MISE18] trends consider IoT and WSN key technologies [SADSF16]. Issues include decentralization, self-configuration, communication and computing architectures. Data management is key, involving decentralised solutions for data ownership and efficient use of IoT resources.

1.2 Theme: Distributed Parallel and High Performance Computing

Two main “technology pushes” shape the landscape of distributed and high performance computing of future Internet: virtualization and many cores version of Moore law. Virtualization drives the transformation of the infrastructure towards cloud, fog or edge. The Moore law, with the end of Dennard scale (2005), provides an increase in the number of cores rather than of the clock frequency, and parallelism is now a must.

Cloud Computing relies upon large-scale datacenters with thousands of servers, providing pervasive and complex ecosystems composed of many heterogeneous entities (from business intelligence to IoT) that interact and adapt their behaviour to changing requirements [VB18]. This increases the importance of: resource optimization and power savings [GC18, CT17, DCMW 17, BCT16]; security preventing data leakage while providing QoS [CM17, SCS17, QCD16]. At the same time is necessary to improve the methodologies for services design [D&al18, MSEJB 16, ANE13].

Multi-access Edge Computing (MEC) is a pillar of next 5G solutions in the areas of IoT and mobile networks [SA16], with strong industrial commitments [OC17, TSM17]. MEC applications include content distribution [LXW17], computation offloading, data preprocessing [NRS17], service migration [KCA15], resource sharing. MEC is a key component in the H2020 5G-PPP and is broadly investigated in the literature [PB17]. Hot topics includes offloading at extremely short time scales, virtualization techniques, optimization models and heuristics [TLG16, DLL16], lightweight orchestration [LAM17, SHL16].

High Performance Computing. Efficient and scalable solutions for analyzing big data are among the most urgent research challenges. Machine Learning (ML) and Artificial Intelligence (AI) can nowadays model complex phenomena by relying on the exploitation of huge training datasets through HPC techniques [ABC16]. Deep Neural Networks (DNNs) accuracy depends on hyper-parameters whose setting require to run massive jobs. Open research challenges include the decentralization/parallelization of learning processes to address efficiency and scalability issues [MBY16] and the efficient deployment of complex models in scenarios characterized by near real-time constraints [DLN16]. Other HPC applications in the field of multimedia processing and simulation need to adaptively exploit heterogeneous resources, accelerators and low-power CPUs [Z17, D&al17, D&al14].

1.3 Theme: Software Engineering

SW systems, such as the SW components of Cyber Physical Systems, are made up of computational elements that work together to control entities of various nature and provide services and innovative applications. They are spatially-distributed, time-sensitive, and multi-scale networked embedded systems, connecting the physical to the cyber world through sensors and actuators. They should ensure reliable behaviour even in unpredictable conditions being also user friendly. These new paradigms sparked novel systems and entire research areas such as autonomous driving, industry 4.0, smart cities, or IoT [EG16]. The goals in this context are, e.g., increasing reliability and safety, reducing resource consumption, improving the performance of processes and usability.

The use of a good SW development process and of support tools is essential to guarantee the development of applications and services that respect the aforementioned requirements. Frameworks for automated Business Process (BP) modelling and analysis are becoming a key technological component in support of BP Management and the continuous growth in complexity and pervasiveness of SW systems calls for the use of modern requirements analysis and formal verification techniques, which may play a key role for guaranteeing the correctness of the systems.

SW systems raise the need to integrate several heterogeneous components and environments into corporate-wide computing systems, and to extend their working boundaries beyond companies into the Internet. The IBM manifesto of autonomic computing [KC03] suggests a promising direction for facing software complexity through self-adaptation, that is the ability to automatically assemble ad-hoc functionality as a response to environment changes or when the user changes requirements [CLG09,LGM13].

Finally, according to Gartner [GAR], there will be nearly 26 billion devices on IoT by 2020. It becomes important that users can configure smart environments consisting of thousands of interconnected devices, which will enable many possible interactions in a user's surroundings. There has been increasing interest in using trigger-action rules for supporting EUD of IoT applications at the commercial (e.g. Tasker [DIN], IFTTT[IFT]) and research level, but trigger-action rule-based approaches can be difficult for non-programmer users because they could raise ambiguity in their interpretation.

2 DIITET Contribution

2.1 Theme: Next Generation Internet

NGI communication technologies beyond 5G and network measurements

<u>Design and optimization of 5G MIMO (**IEIIT**):</u> analysis of 5G (and beyond) systems and their optimization; new algorithms related to the physical and access level of wireless networks; "conventional topics" such as information encoding, signal reconstruction and channel characterization; "emerging topics" such as massive MIMO, cooperative and cognitive systems [CSNZ13] and ultra-low power designs; energy-efficient transmissions for industrial wireless networks [ASS17, SRS14]; optical coherent communications [TBF17]; information-theoretic characterization of the limit performance of systems, optimization of communication protocols and energy resources.

<u>Design and optimization of mobile and vehicular networks (**IEIIT**)</u>*:* new architectures for vehicle-to-vehicle and vehicle-to-infrastructure communications [BZM16,BMZC16] using full-duplexing to increase capacity and reliability [BCM18] [BMZ17]; analysis of the space-time dynamics of the demands for mobile services in urban areas [FFS17]; models and predictors of such demands, for data-driven management of (beyond-)5G networks; mobile edge computing and network slicing [NMS18]; models based on large-scale real-world datasets [MGF17], also for population density estimation and land use detection [FFSZS17].

<u>Satellites and UAV communications (**ISTI**):</u> we are coordinating the *TIM 5G experimentation* in the sites of Bari and Matera in scenarios where UAVs are used. We consider four scenarios, using drones: 1) public safety; 2) radiofrequency jammer detection; 3) monitoring of the electromagnetic field; 4) precision agriculture.

Network measurements (**IIT**): crowd-sourcing techniques to measure the Internet graph via distributed approaches. We involve users on a voluntary basis, overcoming dependencies from operators, and allowing to map up to the Internet edge [GGI17,GIL15].

NGI network paradigms

IoP - Internet of People (**IIT**): IoP is a novel human- and data-centric network paradigm for NGI. DIITET activities include: *data collection*, using human behavioural models to filter data in mobile edge networks [CMP13, CMPR13, MVCP16, M15, MPC17]; *data dissemination*, using human social networking models for data dissemination in mobile networks [ACPD17, ALPC16, BCP10, BP10, BCP08, BCP08b].

ICN – Information centric Networking (**IIT**): solutions for data management compliant with standard ICN architectures for IoT. Our solutions exploit mobile devices forming mobile edge network to provide data-centric access to IoT data [BBP18, BBP16a, BBP16b].

IoT and WSN in NGI and NGI industrial networks

IoT and WSN in NGI (**ISTI, IIT, IMATI**): WSNs for monitoring purposes in naval, home/office, industry and ambient environments for health and wellness, energy consumption, environmental pollution, sleep quality, logistics, cultural heritage; integration of WSN readings in middleware platforms. Network solutions to provide ultra-reliable IoT communications [ABC14]. Measurement of link qualities with minimal overhead and energy waste [AVBM17]. Scalable and reliable transport protocols for IoT [AVBM17, ABVM18]. Resource allocation in shared sensor networks [BB18].

Industrial IoT (**IIT, IEIIT**): fixed, wireless cloud-assisted networks, related to both the "core" and "fog/edge" functions [KRSS18]; information processing, network organization, reliable and real time communications, synchronization and management; distributed architectures and algorithms for dense wireless cloud network platforms [SNSS17], including environmental recognition and vision capabilities in IoT working at high-frequencies and wide bands [SSM16]. Distributed data management in industrial IoT, investigating where and when the data should be moved [RP17, ERS18], the role of nodes for data management [RPC18b], network (re-)configuration for optimal data delivery [RPC18].

2.2 Theme: Distributed Parallel and High Performance Computing

Cloud Computing. (IMATI, INM, ISTI, ICAR) The AP studies optimization techniques for modern datacenters to increase utilization, reduce power consumption, and guarantee security and QoS. We develop optimal placement and consolidation policies using suitable modeling, control, and multi-objective optimization techniques [GC18, GC16b, GC16, GC14]. Workloads of large datacenters are analyzed to devise self-adaptive models able to reduce energy use by keeping the desired QoS [CT17, BCT16QD17, QCD16]. A scalable platform for the combined exploitation of Cloud, mobile and IoT devices is proposed that supports dynamicity and provides location-aware brokering functionalities [ACC+17] [SJS+17].

Edge Computing. (IIT, IMATI, ISTI) We focus on the delegation approach, particularly effective for augmented reality or digital image/video processing [ACM17]. We propose a solution where edge nodes in an SDN-enabled network offer remote execution of elementary computation blocks, providing optimal allocation of incoming requests and monitoring functionalities for the edge servers covering a given physical area.

High Performance Computing (IIT, IMATI, ISTI, ICAR) We target AI and ML algorithms for extremely large datasets by investigating: the reduction of the size of training sets through an intelligent selection of examples [LNP18]; the pruning of ML models to make them compact and fast [LNO18]; evolutionary approaches to optimize DNNs hyperparameters. The efficient deployment of AI/ML models is addressed by dealing with low-level features of modern hardware [LNO15, DLN16, DLN16b]. We address the problem of learning from distributed datasets by considering scenarios where data cannot be moved due to privacy concerns and dynamic settings where nodes and data availability change over time [VPC16, VPC16b, VPC17, VPC17b]. We investigate cognitive models for IoT where devices learn and understand the physical world and can take autonomous decisions as a response to environmental and requirement changes. Finally, we study parallel algorithms and methods for compute-intensive tasks, such as image processing or simulation, run on heterogeneous architectures including low-power processors for edge computing scenarios [GDC15, MCRSD17].

2.3 Theme: Software Engineering

The following sub-themes characterize DIITET activities in this area.

Formal Engineering of Cyber-Physical Systems (ISTI)

The main focus of this activity is on the specification, design, analysis, and verification of the behaviours of CPSs in order to prevent failures and malfunctioning. The development of novel software system design processes is supported by requirement analysis techniques [FDEGG17], automatic formal methods [MFS18], stochastic model-based approaches [MCD17]. When analysing a system's behaviour on the fly/stochastic/statistical/spatio-temporal model checking approaches [BDG17] [CLM18] [BVW17] have been employed.

End user development of internet of things applications (ISTI)

Methods and tools are developed that allow end users without programming experience to customize the context-dependent behaviour of their IoT applications and surrounding appliances and devices through the specification of trigger-action rules. The resulting set of tools is able to support the dynamic creation and execution of personalized application versions more suitable for users' needs in specific contexts of use [GMPS17].

Agents and self-adaptive systems (ICAR)

The Middleware for User-driven Self-Adaptation framework is setting up for dynamically changing system behaviours, according to the current state of the world, the injected goals and the available capabilities. This is an automatic approach to autonomously taking decisions about how to operationalise a given set of goals. The resulting system exhibits strong adaptation features that consist of a software system that can orchestrate existing functionalities as a response to environmental and user requirements changes.

Testing of software systems and services (ISTI, IASI)

Innovative functional and non-functional testing methodologies as well as comprehensive testing approaches for software system-of-systems focused on the selection, prioritization and orchestration to support test case generation and execution are investigated to validate complex functional and/or non-functional properties of applications built from modular and distributed paradigms.

Monitoring and analysis of software architecture and Smart Environment (ISTI)

Model based specification of business process for verification and validation of functional and non-functional properties as well as monitoring and analysis of software architectures easily adaptable to the IoT environments are developed [BCFM18].

Software Verification via Constraint Solving (IASI)

We develop techniques and tools based on Constrained Horn Clause (CHC) solvers [DFPP-17]. These include transformation techniques to automatically generate CHC formalizations of software properties, and to improve the effectiveness of CHC solvers. We are developing a semantics-based verification approach agnostic with respect to the programming language and the properties to be verified.

Modelling and Verification of Business Processes (IASI)

We pursue a logic-based approach to the modelling of very rich process knowledge, including its procedural behaviour, time constraints, data-dependent manipulations, and ontology-related (OWL) knowledge [DFMPP-17]. The goal is to enable automated reasoning on various aspects of the model by using tools developed in the area of Automated Theorem Proving, such as SMT solvers, Constraint solvers, and DL reasoners.

3 Impact

Future Internet activities are at the heart of digital society and of its transformations. The technologies exploited in these activities rely on an Electronic and Component Systems (ECS) Industry that continues to be strong at the European level and still maintains a good participation of Italian companies. Future Internet contributes to mashup ECS technologies into Cyber Physical System, Ubiquitous Computing, Internet of Things, Internet of People and other developments. The applications of the Future Internet are pervasive and pertain a lot of different fields ranging from Industry 4.0, to Well Being, Health Care systems, Secure Society, Energy and others.

Europe is one of the main players in the digital society activities and business. To keep a tight link with European efforts, projects and research agenda are fundamental requirements for Italian research bodies and companies to provide effective impact both from an economic and social point of view.

The advent of the digital society is providing opportunities and threats for the future employment possibilities. While a comment on threats is outside the scope of this document, it is worthwhile to mention that there is a huge request at European level of specialized persons, able to work in Future Internet activities, while there is a significant shortage of these figures. Together with Universities, the CNR labs involved in the Future Internet activities provide top level possibilities to educate and train new professionals. The participation of CNR labs involved in the AP to many national and international projects (see the Appendix) aimed to research, innovation and applications permits to provide unique opportunities to young people. We think that this is a fundamental impact of our activities.

An in-deep quantitative analysis of the scientific impact of our activities is beyond the scope of this report. However, we may put in evidence some qualitative aspects. In most cases, the research groups publish their results in highest quality technical journals (belonging to Q1 and Q2 of the reference sectors) and highly selective conferences. At the same time researchers participate to editorial boards of high impact journals and programme committees of top-level conferences. In addition, they are involved in Expert groups of key EU bodies (e.g., in the area of 5G), and participants to the AP are included in top-level international rankings (such as those of Clarivate Analytics). To keep these scientific capabilities is of paramount importance. The CNR groups working in the Future Internet AP have been able to sustain the quality of their research in the field, despite the increasing difficulties of operating in the research environment, particularly at the national level.

Looking at the active and recently concluded projects in the area carried out by our labs, we get an understanding of the scientific impact of the groups working in the AP. We may notice that impact addresses a wide range of fields, as documented by short project descriptions that the reader may find in the annexes. In some cases, the impact is concerned with enabling technologies such as 5G or Distributed Software design or Cloud thus having a broad range of applications. In other cases, the impact is more focused on a specific target area such as cultural heritage, disaster risk reduction or disposal management, to mention a few. In both cases however the results are quite close to an effective possible exploitation e.g. in an industrial project, or in a new product or service.

At the same time all the scientific and technological activities indicated in the previous Sections provide impact results in different and sometime complementary application areas. It may be of interest to try some classifications of impact of our activities.

We may look at impacts using a per-theme view. We refer to the three main themes listed in the previous Sections, that is NGI, SwEng, and HPC but we also adopt a fourth class “All” for the cases when a mix of the three competences have been exploited. A possible metric is the amount of financial support that the different groups were able to collect considering the last five years of activity. At this regard, we have the following situation: NGI activities collected funds in excess of 2.250 KEuro, SwEng collected more than 660 KEuro, HPC more than 2.380 KEuro and “All” more than 1.325 KEuro. However, this is just a rough measures of effective impact. As an example, one may consider the relevance of SwEng activities that play a very important role at national and international level in the field of rail signalling system. In this case, the SwEng methodologies studied and developed by this AP are of paramount importance to get the desired confidence level in the software development process required by safety figures necessary in railway transportation.

Continuing the per theme analysis we may point out some hot topics. In FP9, the NGI theme will cover both the area of 5G communications and beyond, and the area of Future Internet technologies and paradigms. DIITET is very well placed in both communities. In 5G, in addition to be part of current projects in the area, it is present in the expert groups of Networld 2020, the reference ETP for 5G. In future network paradigms, it is at the forefront of human-centric Internet design, which is one of the key feature of NGI since its conception by the DG CONNECT Director General Roberto Viola. From this standpoint, it is worth mentioning that IIT and IEIIT are supporting, with DIITET agreement, the only proposal for an ESFRI infrastructure in the area of Future Internet, called SILECS, currently under evaluation. In particular, IIT is member of the proposal steering board. For HPC, we expect that edge computing will be increasing its relevance for what concerns architectural aspects, while Machine Learning and similar will play a central role for algorithms. The efficiency and effectiveness of produced solutions will strongly depend on the capacity of exploiting parallel heterogeneous computing systems including low power computing devices.

A complementary view that we may adopt is based on a per-application area classification. A list of area of impacts for our researches and projects include: Energy, both for what concerns its production and its efficient use; Environment, including Disaster risk reduction and waste management; Transport, including railway systems, info mobility and intelligent mobility; Industry 4.0 and leisure industry. With respect to NGI, the DIITET activities are creating impact on all the verticals defined for 5G (https://5g-ppp.eu/white-papers/), i.e., automotive, health, transport, Factories of the Future, Energy and Media. For further information the reader may refer to Annexes of this document.

4 Emerging challenges

NGI. *Communication:* beyond 5G technologies, air interfaces and radio solutions; minimizing CAPEX/OPEX of satellite networks. *Networking*: human-centric network and data management, pervasive data-centric access. *WSN and IoT*: energy consumption, security, integration of heterogeneous technologies, dynamic configuration, particularly in Industry 4.0.

HPC. Cloud asks continuous management of services security, safety and energy issues. Edge asks flexible cooperation of devices with adaptive behaviour. HPC requires portably parallel algorithms for demanding tasks. Solutions embracing the cloud, edge and HPC is an open problem.

SWEng. As long as SW grows in size, complexity, heterogeneity and interconnection, it becomes central it to be versatile, flexible, resilient and robust. Novel SW technologies, approaches for reconfiguration, and scalable formal model-based analysis techniques will increase development productivity preserving the SW quality, safety, security and reliability.

5 Conclusions

This white paper provides a comprehensive summary of the DIITET activities in the area of Future Internet. Future Internet is one of the key “Areas of Intervention” in the EU research agenda (FP9), and is well present in the research agendas abroad, starting from NSF solicitations. In both cases, Future Internet topics are allocated specific funding and objectives, as it is considered an area of active research, in all its dimensions. With respect to the national environment, Future Internet topics permeate the objectives and priorities of the latest PNR, even though it is primarily designed with a vertical application approach, differently from what happens in EU and USA.

The area of Future Internet is clustered around three themes, namely (i) Next Generation Internet, (ii) HPC, and (iii) Software Engineering. This comes from a detailed analysis of the coming FP9 programmes, where themes (i) and (ii) have dedicated areas of intervention, while theme (iii) cuts across several other areas. This classification also maps very well the DIITET contributions in the AP. With respect to NGI, DIITET activities focus on (i) communication issues beyond 5G and network monitoring, (ii) novel NGI network paradigms, and (iii) IoT, sensor networks and industrial Internet. In the area of HPC, DIITET is active in (i) cloud computing, (ii) edge computing, and (iii) high-performance computing. Finally, in the area of software engineering DIITET contributes to research on all the phases of the typical SW engineering process, including formal methods, software monitoring and testing, as well as novel programming paradigms. Significant interactions across the themes is present. A notable example is the area of IoT, which spans across all the three themes with specific activities.

It is worth noting that DIITET is having a significant impact in the area of Future Internet, mobilising 56.24 FTEs spread across 7 Institutes, with funded project amounting to around 6.6 MEuro.

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