Collaborative Visual Environments for Evidence Taking in Digital Justice: A Design Concept

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ABSTRACT

In recent years, Spatial Computing (SC) has emerged as a novel paradigm thanks to the advancements in Extended Reality (XR), remote sensing, and artificial intelligence. Computers are nowadays more and more aware of physical environments (i.e. objects shape, size, location and movement) and can use this knowledge to blend technology into reality seamlessly, merge digital and real worlds, and connect users by providing innovative interaction methods. Criminal and civil trials offer an ideal scenario to exploit Spatial Computing. The taking of evidence, indeed, is a complex activity that not only involves several actors (judges, lawyers, clerks, advisors) but it often requires accurate topographic surveys of places and objects. Moreover, another essential means of proof, the "judicial experiments" - reproductions of real-world events (e.g. a road accident) the judge uses to evaluate if and how a given fact has taken place - could be usefully carried out in virtual environments. In this paper we propose a novel approach for digital justice based on a multi-user, multimodal virtual collaboration platform that enables technology-enhanced acquisition and analysis of trial evidence.

CCS CONCEPTS

• **Computer systems organization** → **Embedded systems**; *Redundancy*; • **Computing methodologies** → Perception; • **Networks** → Network reliability; • **Applied computing** → Law.

KEYWORDS

spatial computing, collaborative environment, digital justice, remote sensing

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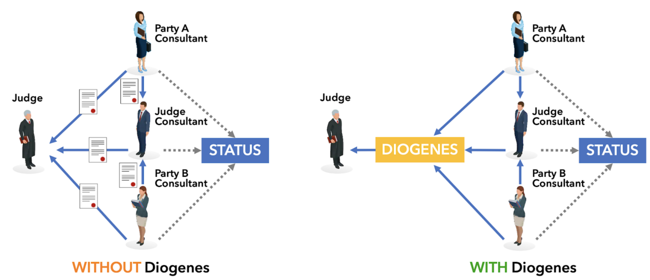

Figure 1: With DIOGENES and without DIOGENES

1 INTRODUCTION

In this work, we present DIOGENES, the design concept of a multi-user, multimodal virtual meeting and collaboration platform for technology-enhanced acquisition and analysis of trial evidence. Stemming from an ongoing multidisciplinary collaboration between researchers in computer science, legal informatics and law, the initiative aims at enabling new forms of collaboration between legal practitioners (synchronous, asynchronous and concurrent) during the investigation and the trial in a robust way by exploiting edge computing capabilities. The strategy proposed is based on the creation and update of digital reconstructions of a real environment where users can add annotations (e.g., documents, photos) while exploring the acquired 3D models in XR, e.g., Augmented Reality (AR), Virtual Reality (VR), or Mixed Reality (MR), together with other users.

As the Greek philosopher carrying a lamp in broad light while looking for the truth, DIOGENES aims at empowering users in the process of collecting evidence for a trial and make them exploit modern devices for 3D scanning crime scenes looking for their "honest man"; i.e., the truth. In general, DIOGENES will: i) push forward the adoption of enhanced technological innovations like 3D scanning and XR solutions into justice administration; ii) provide the context for the consolidation of a shared approach for documentation and visual analytics; iii) enable a better understanding and fruition of trial evidence documentation.

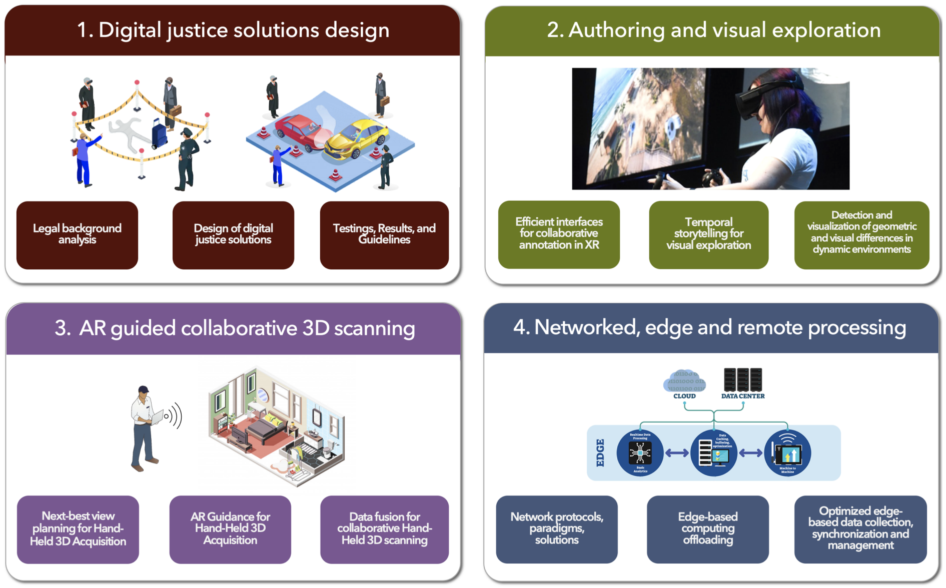

Figure 2: The building blocks of DIOGENES vision.

2 RATIONALE

The approach presented in this paper is rooted in challenges that unfold both on a domain-specific and on a technical level. Here below a brief introduction to each of them.

2.1 Future Perspectives of Digital Justice

Law is probably one of the application and research fields that so far has less taken advantage of information technologies [1]. The administration of justice in particular, regardless the legal system taken into account, has largely fallen behind in exploiting the opportunities offered by data and computation. New ways to make sense of information hidden in legal proceedings remain outside the horizons of judges, clerks and advisors that basically keep using databases accessed via non-intuitive textual interfaces.

It is not by chance then that the EU Commission (see the recent Communication "*Digitalisation of Justice in the European Union. A toolbox of opportunities*" - 2.12.2020 COM(2020)710 final) has identified in the digital evolution of justice a significant goal for the years to come. The quality and efficiency of the administration of justice, on the other hand, is relevant not only for the professionals of justice but also for citizens. To use Commission's words: *"Effective justice systems are also essential for the functioning of the internal market and a prerequisite for economic growth. Access to justice needs to be maintained and to keep pace with change, including the digital transformation affecting all aspects of our lives."*

In recent years, actually, research at the boundaries between law and computer science [2] has stepped up its efforts to turn the power of available technologies in enhancements for the efficiency and quality of justice administration. XR technologies, to give an example, have been employed to perform virtual walk-through of crime scenes [3] while other authors [4], have tackled the integrated use of mobile devices and virtual reality to support Crime Scene Investigation (CSI), enhance the efficiency and effectiveness of investigation while strengthening scientific evidence and reducing the possibility of erroneous conviction. Despite all of that, the applications of Collaborative Virtual Environments (CVEs) [5] for collaboration and interaction of possibly many participants that may be spread over large distances or remote sensing technologies, like LIDARs (Light Detection and Ranging) that remain largely outside legal practice [6].

The foregoing makes it clear the reasons of interest for novel approaches and tools supporting judicial activities. As above highlighted, a particularly promising scenario, from this perspective, is offered by those activities that, like evidence taking, involve several actors and require topographic surveys of places and objects or those that, like judicial experiments, could be usefully carried into a virtual environment. The introduction of advanced information technologies in their workflows could not only in crease the effectiveness of justice administration but also: *i*) foster more empirically grounded approaches to the analysis of judicially relevant facts; *ii*) innovate the way evidence law tackles the design of its own procedures.

2.2 Technological Challenges

DIOGENES tackles several implementation challenges on different technologies, including 5G, Edge Computing, and XR. In detail, 5G network technologies are evolving rapidly, exhibiting high potential for adoption and exploitation by industry verticals to serve advanced networking needs. Indeed, XR is one of the most disruptive vertical markets that will benefit from 5G, as such a vertical market demands strict throughput and latency requirements that are not feasible with today's technologies. It is envisioned as a key enabler for next-generation applications, a stronger and wider interplay of 5G networks with edge technologies, to bring the computing and storage resources closer to the end-users in a transparent, reliable and secure way.

In particular, it is foreseeable that DIOGENES can contribute to the spreading and adoption of the Multi-access Edge Computing (MEC) to support XR technologies. DIOGENES aims to explore and expand state of the art for authoring XR experiences lowering the barrier of entry to create collaborative XR experiences drastically, opening opportunities for more users to create experiences. Indeed, to support simultaneous access to and modify XR experiences by multiple users, an authoring tool is the key to having an easy-to-use visual design content creation. This enables fast iteration cycles based on the timely feedback of the changes being made, which is a known advantage of collaborative environments from other technology areas that have been impossible for XR creation.

From a technical point of view, modern remote sensing technologies, like 3D sensors, and a next-best view (NBV) planner to enable collaborative scanning, to optimize 3D data acquisition, and to assure completeness of exploration [7], which is an important aspect in legal procedures. Common approaches for NBV planning in the robotics domain consist of volumetric algorithms based on 3D occupancy maps and ray casting. Probabilistic NBV methods store a value in each occupancy map cell that represents the probability of occupancy. For example, Daudelin et al. [8] proposed a probabilistic NBV framework for a mobile robot to perform incremental reconstruction of the 3D shape of an object. Non-probabilistic methods were also proposed [9–11]. In [9] a sampling-based algorithm was proposed.

In [10] a method was developed to explore objects based on saliency of point cloud segments, while in [11] a NBV planner was introduced to explore regions of space where changes are more likely to have occurred, due to user manipulation actions. Few works have addressed systems where a human is guided towards the next computed view to scan an environment [12–14] using a handheld device (smartphone/tablet). Andersen et al. [12] proposed a method that provides visual feedback to the user by exploiting augmented reality, but this approach did not exploit a next best view planner as all the views were computed in advance. Other approaches based on NBV planning did not include augmented reality [13, 14]. Moreover, they are computationally slow [13], and limited to scanning a single object [14].

All previous works did not consider collaborative scanning. Although handled devices are now computationally powerful, running computationally demanding apps is still problematic due to limited battery capacity. Therefore, DIOGENES needs offload processing to a standard centralized cloud [15, 16]. Unfortunately, this introduces a significant execution delay that makes the offloading unsuitable when requiring a satisfactory QoS (Quality of Service) and QoE (Quality of Experience) [17–22]. To cope with the delay problem, a new emerging concept, as edge computing, has been introduced, rooted on the "cloudlet" concept [23]. Edges bring computation and storage closer to the devices enabling execution of highly demanding applications while meeting strict delay requirements [24].

3 THE DIOGENES APPROACH

Based on the rationale above, we propose a novel approach bringing together mobile remote sensing technologies, XR and SC, to create a new generation of immersive, interactive and collaborative environments for information retrieval and knowledge mining in digital justice. Seen as a whole, our idea converges different technologies and methodologies into a unique vision geared towards allowing users involved in judicial activities to build, update, annotate, and explore 3D models of real environments. The vision rests on four basic components, four "building blocks" we describe in the following (see Figure 2.)

Digital Justice Solutions Design. The first building block is the analysis - carried out from the point of view of scholars from law and computational legal studies - promoting the seamless and coherent integration between domain specific needs, technologies and design choices. A wise and informed use of enhanced technologies calls for a detailed description of needs and legal constraints characterizing the taking of evidence in civil and criminal trials, and a series of design proposals drawing from legal informatics research capable of turning the power of available technologies in enhancements for the efficiency and the quality of justice administration. Such activity should be inspired by the following domain-specific guiding principles:

a) Enhance and augment evidence taking and analysis: XR and NBV technologies can be used to enhance and "augment" both topographic surveys and judicial experiments. Indeed, replacing "handmade" topographic surveys - taken with measuring tape with detailed 3D models generated in real-time by integrating LIDAR and GPS - do not simply allow more accurate measurements, but opens up completely new horizons to the judicial acquisition and the analysis of evidence. 3D environments can also be used to carry out "in silico" trial experiments very rarely exploited in real trials.

b) Empower fairness: the tight integration between intuitive and reliable technologies, open source solutions, and transparent collaborative workflows can prove to be crucial to allow the parties at trial to more easily assess the correctness of evidence acquisition and analysis with positive spillovers on proceedings fairness.

c) Enable collaborative evidence data annotation and analysis: a further priorities is the design of solutions allowing to link different types of information (timestamps, GPS coordinates, normative references, court documents, etc.) to the data coming from the digital acquisition of evidence.

An ideal testbed for our approach could be a road accident where there may be damages and/or victims. In such a scenario, a reconstruction of the accident dynamics is necessary. Usually evidence taking take place with technicians, lawyers of all involved parties and judge's technical consultant. Each subject prepares a report containing data and assessments associated with the scenario's various elements. Before the ruling, the judge asks for a judicial experiment needed to assess the reliability of the reconstructions of accident dynamics proposed by the parties involved. All such activities - typically carried out using printed documents (basically reports and appraisals) - could be enhanced by DIOGENES' methodology and technologies running on edge infrastructure. In addition, all stakeholders could be able to acquire, edit and annotate data, and explore the evidence in full, eliciting changes and limiting bias.

AR Guided Collaborative 3D Scanning. A Next Best View (NBV) algorithm predicts the best pose where a sensor (depth camera) should be placed to gather the most possible information about the environment. By applying a NBV algorithm iteratively, and by moving the sensor to the planned view poses, it is possible to perform exploration tasks until a termination condition is met (e.g. the environment is fully explored). A NBV algorithm maximizes an information gain that estimates the amount of volume that would turn into occupied or empty if observed from the planned viewpoint.

Next-best view algorithms are usually computationally expensive, as they need to simulate sensor measurements from many candidate view poses. The problem that will be addressed in DIOGENES is even more challenging, compared to the state of the art approaches for several reasons. First, performing an in situ 3D scan by using mobile devices involves technological issues related to limited computing power, battery life and storage capabilities. Second, DIOGENES will enable multiple users to perform 3D scanning even concurrently. Third, 3D scanning will require accurate self-localization of the mobile devices in a common reference frame. Fourth, a visual feedback should be provided in real-time as guidance to the user so that the handheld device can be placed in the computed NBV pose. DIOGENES will include a next-best view planner that will be developed to compute the best pose of a mobile device to take a new 3D image, given the current 3D representation of the environment and the current pose of the handheld device. DIOGENES will exploit advanced mobile devices like the iPad Pro. Device self-localization will be performed by applying visual odometry and 3D mapping algorithms. The NBV planner will support multiple devices concurrently by exploiting the network infrastructure. Methods will be investigated to optimize not only the information gain of each observation, but also to minimize the total path length traveled by the mobile device. An augmented reality visual feedback will be generated on the mobile devices to help the users in the scanning process by displaying directional navigation clues in real-time. Visual navigation clues will be computed by each mobile device, given the current estimated pose of the device in the environment and the next-best view to be reached by the 3D camera of the device. Navigation clues (3D translation and 3D rotation) will include virtual arrows and other indicators to guide the user to the next best view pose. Thanks to the distributed computing infrastructure a 3D representation of the whole environment will be maintained and updated by registering together all 3D data collected by the different handheld devices. The updated environment representation will be used in turn as input for the execution of the next-best view planner, and it will be stored and made available for Edge-based computing and 3D authoring.

Authoring and Visual Exploration. The proposed approach aims at creating a multi-user environment where multiple stakeholders with different roles can work together on an XR story project and where they can contribute at the same time as illustrated in Figure 3. Those stories which represent XR spaces are inherently complex and often require many domains of knowledge to be completed and made appealing to a viewer. Therefore, authors shall be empowered to work on such stories in parallel to minimize time-to-finish and enable them to gain the advantages from real-time collaboration. Furthermore, this authoring method shall allow users to work on the story in an immersive environment that aids the creative process by experiencing the immersion of content during the editing process. To achieve these goals, DIOGENES must tackle many technical challenges. The authoring process can host several users at the same time collaborating during the co-creation process, and must support the most popular XR head-mounted-display devices and input devices. Finally, scene management requires merging events and keeping data consistent among different users during the creation. Efficient interfaces for collaborative annotation in XR will design appropriate 3D interaction techniques for XR environments in terms of objects, interaction, and system interaction. These interactions can be: a) Locomotive (actions to allow users to move in a scene); b) Actions on objects or space (actions to allow users to move, scale, rotate, and modify the properties of 3D objects in the scene); c) Actions on the system (accessing menus, selecting tools, and inserting annotations like photographic surveys, audios/videos, and proceedings). In addition, this interface will implement all the cooperative and collaborative virtual environment features used to distribute the virtual space among the clients. These features will be developed considering distributed concurrent interactions in the virtual space enabling automatic synchronization of contents between clients to support concurrent and cooperative operations. Temporal storytelling for visual exploration will explore the interactive aspects of the XR with timeline storytelling features. Here, DIOGENES will introduce a method of allowing the user to experience changes in both the 3D virtual environment and time as an additional dimension of the user and the author's control. The timeline storyteller will be used to present 3D data in a temporal sequence utilizing a palette of timeline representations, scales, and layouts, as well as controls for filtering, highlighting, and annotation. Detection and visualization of geometric and visual differences in dynamic environments will explore the possible use of existing metrics and visualization methods for detecting changes between different 3D captures of the same location performed at different moments in time. In addition, methods will be validated to design metrics to determine meaningful changes in a virtual environment. Finally, DIOGENES will explore efficient and effective visualizations of such changes using either traditional methods or XR modality validated by users' studies. Visualization of changes is crucial because only the important information needs to be reported to avoid users being overwhelmed.

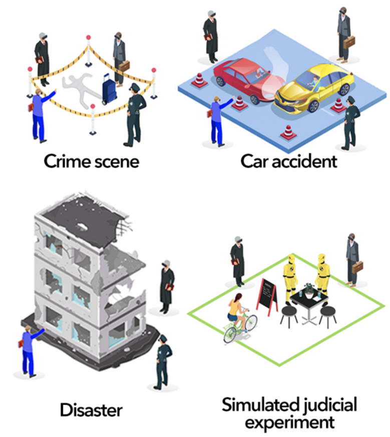

Figure 3: Example scenarios of evidence taking that involve several actors such as judges, lawyers, clerks, advisors.

Networked, Edge and Remote Processing. The multi-user, multi-modal virtual meeting, and collaboration environment envisioned in DIOGENES calls for a computing and communication platform able to satisfy the demanding requirements of 3D acquisition processes as well as a collective creation of the virtual environments and its consequent management. The computing and communication platform standing at the basis of DIOGENES is requested to provide computational capacities that go beyond the one of a hand-held device (like the ones used for 3D acquisition processes). At the same time, it needs to be accessed with very limited network latency and sufficiently large bandwidth.

In order to match these requirements, DIOGENES computing and communication platform builds upon the edge paradigm to provide computing and storage capacities with an on-premise and contextualized computing infrastructure. This, in turn, poses a key requirement for the efficient exploitation of such resources, which need to be properly accessed and leveraged. As a consequence, the computing and communication platform supporting DIOGENES leverages novel solutions enabling an edge-based processing of the computations requested by the collaborative 3D-based virtual environment creation and management. The approaches underpinning DIOGENES relies both on hand-held devices and more powerful edge resources in order to serve as capacitor for processing the computational tasks as well as to provide efficient ways to optimize the distributed collection and management of data.

From an operative viewpoint, the computing and communication platform of DIOGENES is a compound of technologies, network protocols and solutions serving as the basis on which to build the computing offloading and data management activities. These technologies enable the offloading of the computations from the hand-held scanning devices (like next-best view planning) to the edge infrastructure. This task will provide the means for enabling a seamless and transparent usage of edge resources for processing computational-demanding tasks, that could otherwise overload hand-held devices impairing the QoE of end-users or drain the batteries, significantly reducing the operative time of devices and operators. The computing and communication platform supports efficient data collection, management and synchronization in the edge-empowered computing infrastructure. Data management and organization mechanisms target both the need of a single edge node and also the cooperative work involving multiple edge resources.

4 CONCLUSIONS

However tentative, the idea of a technology-enhanced support to acquisition and analysis of trial evidence appears to be promising and worthy of further deepening for a variety of reasons. This is real first of all for the legal domain where the availability of precise, intuitive and collaborative tools could prove extremely beneficial for the efficiency of justice administration, for quality of work of legal practitioners and to ease the determination of truth by limit bias during litigation. From a technical point of view, the creation and the update of real environments' digital reconstructions exploiting next-best view planning, distributed multi-sensor data fusion, and multi-user guidance to perform a 3D scan through AR is a challenging endeavour that will enable a higher Quality of Experience. The DIOGENES approach will be developed and applied to different contexts such as investigative journalism, which has just recently started to exploit immersive and spatial visualization technologies.

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REFERENCES

[1] N. Lettieri. Knowledge machineries. introducing the instrument-enabled future of legal research and practice. In *Law via the Internet*, pages 10–23, 2018.

[2] N. Lettieri. Law in the turing's cathedral: Notes on the algorithmic turn of the legal universe. In Woodrow Barfield, editor, *The Cambridge Handbook of the Law of Algorithms*, pages 691–721. Cambridge University Press, 2020.

[3] Till S., Akos D., Raffael A., and Lars C. E. Applying virtual reality in forensics–a virtual scene walkthrough. *Forensic Science, Medicine and Pathology*, 15(1):41–47, 2019.

[4] C. Lee, Y. Fang, Y. Huang, S. Lee, and W. Chen-Chung Yeh. Application of wearable devices in crime scene investigation and virtual reality. In *2019 IEEE Symposium Series on Computational Intelligence (SSCI)*, pages 206–210, 2019.

[5] N. Capece, U. Erra, G. Losasso, and F. D'Andria. Design and implementation of a web-based collaborative authoring tool for the virtual reality. In *2019 15th International Conference on Signal-Image Technology Internet-Based Systems (SITIS)*, pages 603–610, 2019.

[6] U. Erra, D. Malandrino, and L. Pepe. Virtual reality interfaces for interacting with three-dimensional graphs. *International Journal of Human–Computer Interaction*, 35(1):75–88, 2019.

[7] M. Giorgini, S. Marini, R. Monica, and J. Aleotti. Sensor-based optimization of terrestrial laser scanning measurement setup on gpu. *IEEE Geoscience and Remote Sensing Letters*, 16(9):1452–1456, 2019.

[8] J. Daudelin and M. Campbell. An adaptable, probabilistic, next-best view algorithm for reconstruction of unknown 3-d objects. *IEEE Robotics and Automation Letters*, 2(3):1540–1547, 2017.

[9] M. Selin, M. Tiger, D. Duberg, F. Heintz, and P. Jensfelt. Efficient autonomous exploration planning of large-scale 3-d environments. *IEEE Robotics and Automation Letters*, 4(2):1699–1706, 2019.

[10] R. Monica and J. Aleotti. Contour-based next-best view planning from point cloud segmentation of unknown objects. *Autonomous Robots*, 42(2):443–458, 2018.

[11] R. Monica, J. Aleotti, and S. Caselli. A kinfu based approach for robot spatial attention and view planning. *Robotics and Autonomous Systems*, 75:627–640, 2016.

[12] D. Andersen, P. Villano, and V. Popescu. Ar hmd guidance for controlled hand-held 3d acquisition. *IEEE transactions on visualization and computer graphics*, 25(11):3073–3082, 2019.

[13] A. Locher, M. Perdoch, H. Riemenschneider, and L. Van Gool. Mobile phone and cloud — a dream team for 3d reconstruction. In *2016 IEEE Winter Conference on Applications of Computer Vision (WACV)*, pages 1–8, 2016.

[14] F. Langguth and M. Goesele. Guided Capturing of Multi-view Stereo Datasets. In M.-A. Otaduy and O. Sorkine, editors, *Eurographics 2013 - Short Papers*. The Eurographics Association, 2013.

[15] P. Mach and Z. Becvar. Mobile edge computing: A survey on architecture and computation offloading. *IEEE Communications Surveys*, 19(3):1628–1656, 2017.

[16] Massimo Coppola, Patrizio Dazzi, Aliaksandr Lazouski, Fabio Martinelli, Paolo Mori, Jens Jensen, Ian Johnson, and Philip Kershaw. The contrail approach to cloud federations. In *Proceedings of the International Symposium on Grids and Clouds (ISGC'12)*, volume 2, page 1, 2012.

[17] Ranieri Baraglia, Patrizio Dazzi, Matteo Mordacchini, Laura Ricci, and Luca Alessi. Group: A gossip based building community protocol. In *Smart spaces and next generation wired/wireless networking*, pages 496–507. Springer, Berlin, Heidelberg, 2011.

[18] E. Carlini, M. Coppola, P. Dazzi, M. Mordacchini, and A. Passarella. Self-optimising decentralised service placement in heterogeneous cloud federation. In *2016 IEEE 10th International Conference on Self-adaptive and Self-organizing Systems (SASO)*, pages 110–119. IEEE, 2016.

[19] G. Anastasi, M. Coppola, P. Dazzi, and M. Distefano. Qos guarantees for network bandwidth in private clouds. *Procedia Computer Science*, 97:4–13, 2016.

[20] M. Bertolucci, E. Carlini, P. Dazzi, A. Lulli, and L. Ricci. Static and dynamic big data partitioning on apache spark. In *PARCO*, pages 489–498, 2015.

[21] A. Lulli, L. Ricci, E. Carlini, P. Dazzi, and C. Lucchese. Cracker: Crumbling large graphs into connected components. In *20th IEEE Symposium on Computers and Communication (ISCC) (ISCC2015)*. IEEE, 2015.

[22] M. Danelutto, P. Dazzi, et al. A java/jini framework supporting stream parallel computations. In *PARCO*, pages 681–688, 2005.

[23] M. Satyanarayanan, P. Bahl, R. Caceres, and N. Davies. The case for vm-based cloudlets in mobile computing. *IEEE Pervasive Computing*, 8(4):14–23, 2009.

[24] J. Altmann, B. Al-Athwari, E. Carlini, M. Coppola, P. Dazzi, A. Juan Ferrer, N. Haile, Y. Jung, J. Marshall, E. Pages, et al. Basmati: an architecture for managing cloud and edge resources for mobile users. In *International Conference on the Economics of Grids, Clouds, Systems, and Services*, pages 56–66. Springer, Cham, 2017.