

Leveraging Crowdsourcing and Crowdsensing Data for HADR Operations in a Smart City Environment

Manas Pradhan, Frank T. Johnsen, Mauro Tortonesi, Sabine Delaitre

Abstract—The future of the world's population concentration lies in the bounds of the urban cities. Citizens or humans are the most important tangible resources in a Smart City environment who need to be served as well as protected. The concept of Smart Cities is trying to accomplish the idea of serving the citizens by leveraging the potential of Information and Communications Technology (ICT) assets. The citizens have access to Smart technologies and applications, and thus they form an indispensable component to complement and supplement a Smart City's operation. Especially in a Human Assistance and Disaster Recovery (HADR) operation where a Smart City's core infrastructure might get compromised, the assets of citizens can be put to use. This paper aims to describe the current state of affairs for safety in cities and humanitarian assistance in emergency situations, which require leveraging Situational Awareness (SA) data. We discuss and propose mechanisms for connecting to and utilizing Crowdsourcing and Crowdsensing data in a Smart City environment which can assist in efficient HADR operations.

Index Terms—Smart City, IoT, HADR, Safety, Interoperability

1 INTRODUCTION

MAN-MADE and natural disasters, compounded in intensity and frequency by degrading climate issues, represent the biggest threat to human civilization. These disasters occur suddenly with unforeseen impacts. Even a small impact in a city environment has the potential for causing large scale losses, of both humans and financial assets, often causing a domino effect of emergency situations. Recovering from such widespread destruction requires a lot of time and effort. The cities of tomorrow need to be prepared for these exigent conditions by preparing for Humanitarian Assistance and Disaster Response (HADR) operations. In Smart City scenarios, if the appropriate tools for HADR operations are in place, then the losses can be avoided to a large extent with a quicker turnaround time. Leveraging the technology a Smart City has, particularly its Information and Communications Technology (ICT) capacities, adds valuable new opportunities for HADR operations. These ICT tools from the Smart City may augment the traditional methods and tools employed by emergency responders for disaster recovery.

The challenges that Smart Cities incur due to humans concentrating in a confined area can be used to the advantage of HADR operations. Citizens have access to Smart devices which sense and actuate on behalf of the users. The familiarity of users with their devices and associated applications provides the opportunity to use the human resources in the city periphery to provide precise and recent ground-level information. These human sources of information can be leveraged using the concepts of "*Smart Crowdsourcing and Crowdsensing*". The existing Smart City ICT assets can utilize this huge collection of information from smart devices, such as Smart phones, Smart home appliances, Smart watches, etc., to aid the emergency responders by providing them necessary Situational Awareness (SA).

The term "*Crowdsourcing*" introduced in 2005 by Jeff

Howe and Mark Robinson aimed at showcasing how businesses were using the Internet to *outsource work to the crowd* [1]. It can be defined in the current context as "*a type of participative internet-based activity*", which can be either paid or unpaid based on the purpose and audience. The participant individuals, institutions, or companies propose the task to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call.

Crowdsourcing involves people, who participate by bringing their work, money, knowledge and/or experience to achieve mutually beneficial objectives. Commitment can range from people simply filling out singleton questionnaires about food preference to participation in long-term studies by providing daily inputs about their health parameters.

The term "*Crowdsensing*" stems from Crowdsourcing, and refers to the participatory collection of data from sensors instead of people [2]. In the context of HADR operations, Crowdsensing typically leverages personal mobile devices (such as smart phones, tablet computers, wearables etc.) as sensing and computing platforms. These devices can collectively share data and extract information to measure, map, analyze, estimate or infer (predict) relevant information. Especially the vast usage of social media applications, where citizens are involved in consuming and reporting variety of information, encompasses this context properly. ICT assets deployed across the city either by city administrations or private firms could also be exploited in Crowdsensing applications. Examples range from the fire detection sensors installed on the buildings to the edge devices which are associated with street cameras for detecting and monitoring crowd in public places.

Crowdsourcing and Crowdsensing resources can seamlessly contribute to the Smart City ICT while doing their everyday tasks. Generally these resources would contribute

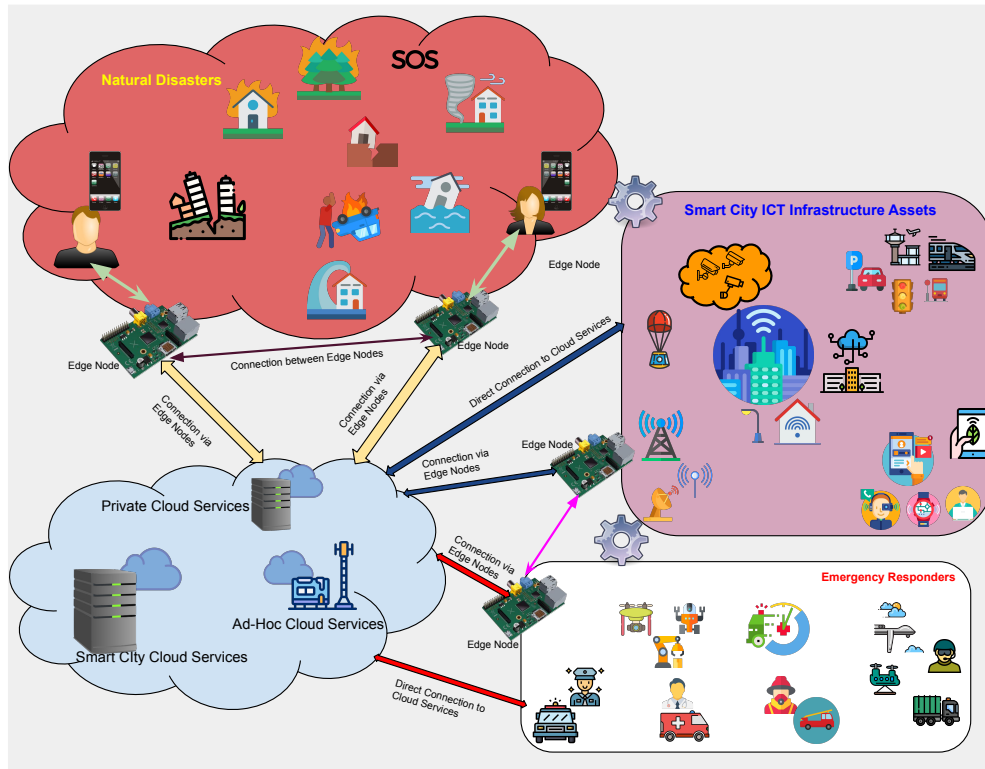


Fig. 1. Smart City HADR Operations Scenario using ICT Technologies

in an *opportunistic* or *participatory* manner, i.e., either contributing due to some paybacks or voluntarily. However, considering the circumstances of a disaster situation, we can assume the voluntary participation of a large portion of citizens, as well as individuals from various organizations. Participation would entail the active involvement of people contributing sensor data such as pictures, rescue requests, etc., related to a disaster phenomenon. Also, the sensing effectiveness can be increased significantly by reducing user involvement through automation, e.g., leveraging street cameras to detect human casualties in an area, or using continuous location sampling of users in an affected area through their mobile GPS signals.

2 SMART CITY HADR SCENARIO

Fig. 1 shows an overall scenario setup for HADR operations in a Smart City, involving both already present ICT assets as well as the ICT assets deployed by the emergency responders. HADR operations could involve a broad range of responders, including governmental agencies such as the police, fire brigade, medical personnel, military and para-military agencies etc., as well as non-governmental agencies such as Red Cross, humanitarian organizations from other cities or countries, etc. These agencies might deploy their own ICT assets such as sensors, actuators, mobile communication towers, control rooms, smart phones and applications etc. In a Smart City scenario, SA can be vastly complemented by utilizing the existing data and infrastructure assets from the Smart City domain. Such assets include Cloud services, mobile phone users with interactive applications, deployed cameras, sensors and actuators etc.

Crowdsensing agents, i.e., either private citizens or emergency responders using interactive applications, can send SA data to be acted upon. These applications can be specifically designed for disaster recovery usage or social media applications where individuals report a variety of activities. Reports could be in the form of text, explicit alarm notices, and may include photo and video content for verification of the activity. Similarly from the other end, these applications can provide users with status information about the HADR operations, and also asking them to contribute specific information or issuing alerts. Distributed human intelligence from the ground level can allow responders to pinpoint their actions for faster rescue and relief.

As shown in Fig. 1, end-user applications can send their data either to the edge nodes or to Cloud servers. The dawn of *Edge Computing* can further accelerate HADR operations by selecting and filtering out relevant information that can be disseminated based on use-cases. Edge devices can exchange relevant information with higher echelons, such as centralized servers which can process and compute further to provide a common SA that can be shared between the participating HADR agencies. Based on the control information disseminated, along with the traditional relief transport vehicles such as air and land vehicles, devices such as drones, land robots (autonomous or manually controlled) can be actuated to transport relief material and personnel. These drones and land robots can also be used for autonomous reconnaissance of the affected areas.



Fig. 2. Command Post of the safety solution in the Seville council for the Holy week.

3 EXISTING CROWDSOURCING AND CROWDSENSING RESEARCH PROJECTS

There have been multiple approaches for Crowdsourcing and Crowdsensing in various parts of the world which are directed towards assisting citizens and emergency responders. Some of these real-world implemented approaches are listed in the following.

3.1 Implemented Projects

3.1.1 Public Safety Management by Wellness Telecom

Wellness Telecom demonstrated an innovative project around Public Safety Management that was carried out during the Holy Week festival in Seville in April 2018 [3] and 2019. It aimed at ensuring the safety of large congregation of visitors and residents during the week long celebrations. A centralized intelligent management platform was connected to:

- 1) Cognitive video platforms using CCTVs, for video surveillance to detect people flow, crowding, dangerous objects and stampedes.
- 2) Smart barriers to send alerts when movement, displacement and separation were detected.
- 3) Smart lighting installed in high-risk areas.

This platform with the close collaboration of police authorities ensured and coordinated citizen safety to prevent incidents and public disturbances in the crowded city center. The platform enabled the city to be responsive in real-time to any possible incidents.

Holy Week is a traditional festivity that attracts over one million visitors to Seville, filling its streets with crowds 24 hours a day. In 2018, the Safety solution worked with 173 connected streetlights and 100 cameras, and a command post installed with the Seville council. Fig. 2 shows the command post where 7 processions were simultaneously monitored as displayed in the left screen. During both editions, no critical emergency situations occurred except for some safety issues that were handled quickly using the safety system deployed. Based on this experience some needs

appeared with respect to SA like fostering the synergies with safety managers and boosting the monitoring capacity of the current solution. WT plans to develop and integrate a fog node solution based on the UNE 178108 standard, thus targeting an innovative IoT service that harnesses compute and memory resources at the edge. This new solution will have the potential to empower SA drastically in terms of scope and accuracy and bring more resilience to the system. It would do so by improving the real time geo-monitoring (geo-positioning of monitored assets) service and by monitoring not only static assets but also mobile ones (like wearables). It would also incorporate the objective of building an advanced dashboard (a powerful map-based analytics) supporting decision-making where all monitored assets will be displayed in real time.

3.1.2 MONICA

Management of Networked IoT Wearables Very Large-Scale Demonstration of Cultural and Societal Application (MONICA) is an EU Horizon 2020 (H2020) project. One of its goals is to utilize Crowdsourcing and Crowdsensing to meet security challenges and improve user experience at big open-air cultural and sports events. It aims at large-scale implementation in cities using legacy and IoT solutions involving huge crowds [4]. It targets usage of user devices such as smart wristbands, mobile phones and smart glasses, and installed video cameras, loudspeakers etc. Using these devices, a portfolio of applications are offered for enhanced city services. These pilot implementations are demonstrated in six European cities namely: Bonn, Hamburg, Copenhagen, Leeds, Lyon and Torino, involving thousands of application users. Some of the intended use-cases handled in this project are:

- 1) Detecting and redirecting high-risk queues.
- 2) Detecting, reporting and handling health incidents.
- 3) Reporting and locating missing persons.
- 4) Detecting, reporting and handling security incidents.

Application in Tivoli and Leeds

In Tivoli, Copenhagen, the Tivoli Garden's Friday Rock Concert attracts millions of visitors a year. MONICA's crowd and capacity solutions were deployed in conjunction with Tivoli's existing security setup. The aim was to improve on the existing methods for guest counting, minimizing large crowd movement and behavior in the concert areas. In addition, it aimed at developing an early crowd warning system for the critical entrances at the venue to minimize crowd build-up. Surveillance cameras installed counted the number of people in the areas, monitored direction and crowd flow. They detected and sent early warnings through the Common Operational Picture (COP) enabling the command center to notify personnel.

Similarly, at the Emerald Headingley Stadium in Leeds, video analytics and counting algorithms were used for gate counting, crowd size estimation and congestion monitoring. The counting algorithm performed very well against existing algorithms with a counting accuracy of 72 %.

3.1.3 CAGED

Communication Application with Geographical Element Data (CAGED) is an application developed by the Norwegian Defence Research Establishment (FFI) for its Home Guard division [5]. This app uses the concept of Crowdsourcing and Crowdsensing for collecting and sharing SA data between individuals. In addition, the app usage involves the concept of Bring Your Own Device (BYOD) where the home guard soldiers would bring their phones and use the developed Android application on their phones.

Experimentation in Eastern Norway

The SMART project targets the Command and Control (C2) needs of the Norwegian home guard. The Norwegian home guard performed SA experiments using Android smart phones and the CAGED app in Eastern Norway over diverse terrains as a part of the SMART project. The idea was to use smart phones as a cheap and low complexity platform for collaboration and provide SA for the Norwegian home guard. The application used unclassified information and coupled the smart phone information flow with dedicated devices for the area forces. The exercise in Eastern Norway provided support for blue force tracking, observation reports with text, sound and images, instant messaging (chat), and document distribution. The users could discover other users using the app and locate them using OpenStreetMaps. The experimentation demonstrated the idea of shared SA between the participants while keeping the centralized server (control room) in the loop. Fig. 3a shows a screenshot of the CAGED app with a background map and icons showing the status of the various observations. Fig. 3b shows the desktop counterpart running at the command post showing the observations input by the guards.

The users reported the usage of the app to increase their SA and their operational effectiveness. The measurements for app usage were evaluated for Information quality, attitude and satisfaction, system quality etc. The positive outcomes involved guards having a good overview of their squad and their ability to enter observations flawlessly. On the other hand, the cons involved users reporting poor map basis, imprecise GPS positioning, and tough working with observations.

3.1.4 CrowdFlower

CrowdFlower is a platform that aims at Crowdsourcing data involving verification, finding trusted sources, and deciding the *Value-of-Information* (VoI). It is cloud-based with features for training Artificial Intelligence (AI), machine learning while keeping human-in-the loop [7].

Application during Haiti Earthquake

The platform was re-purposed during the Haiti earthquake to be offered as a service [8]. Since the Haiti's cell tower infrastructure remained intact, the platform was used by disaster-struck people to send text messages asking for relief. It used a text-message translation tool to aid Mission 4636. Any individual could text the code 4636 from their phones for free to get help. The Kreyol-speaking volunteers in turn translated and classified the messages for aid workers to send relief. Over 40,000 SMS were received over the system with the platform able to handle upto 5000 SMS at a time.

Apart from the already tried and explored projects mentioned above, Fig. 4 shows some interesting upcoming projects and initiatives for Crowdsourcing and Crowdsensing which could potentially be used for HADR operations in Smart Cities.

3.2 Takeaways from the Implementations

Based on debriefing sessions, project reports and implementation evaluations, the following present the lessons learnt and the applicability of the above solutions as drivers for Smart City ICT usage:

- Shared SA based on data sharing approach using internet connectivity which supports large volume of data flow and real-time data collection from heterogeneous sources.
- Fostering trustworthiness of data through standardised APIs and data formats for exchanging data.
- Trusted framework covering key elements such as shared data, participating actors/ devices and infrastructure to ensure unhindered data flow.
- Close collaboration with cities and decision makers not only for a better and effective planning but also to enable cloud platforms to be operational over necessary network infrastructure.

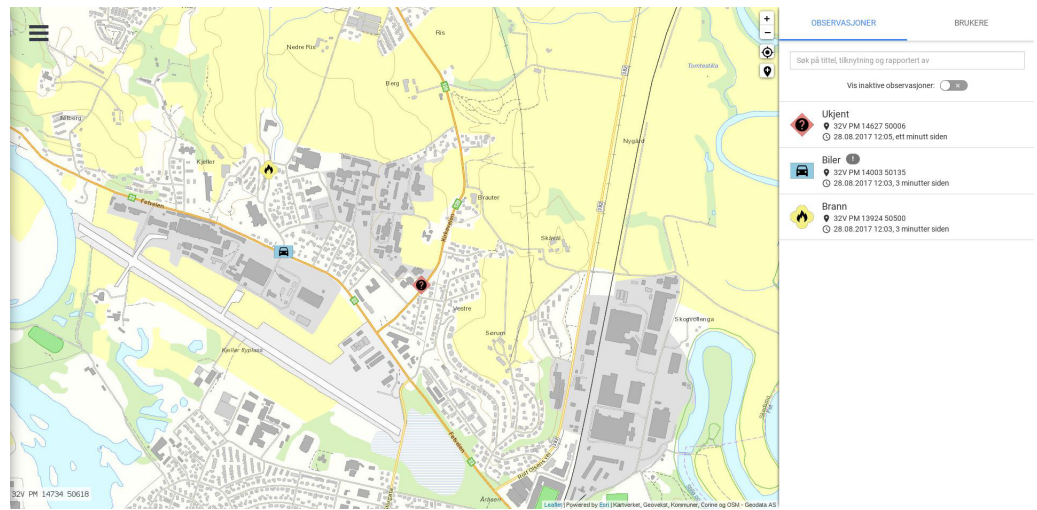
The solutions also present challenges discussed in section 4, and the capacity to tackle them will convert the solutions into resilient ones.

4 OUTSTANDING CHALLENGES AND POSSIBLE SOLUTIONS

The existing solutions mentioned in 3 can be extended or adapted for future HADR operations. But there exists multiple limitations in the way the Smart City ICT is structured, which prevents an organized approach for utilizing the Crowdsourcing and Crowdsensing applications and methodologies. Below are some of the major challenges and some proposed or existing approaches to deal with the challenges.



(a) CAGED app showing shared Situational Awareness data [6]



(b) METIS Desktop app showing Situational Awareness data at Command post [6]

Fig. 3. SMART Experiment with the Norwegian Home Guard.

4.1 Interoperability aspects in the ICT domain

There is a lack in standardization in Smart City Application Programming Interfaces (APIs). Each city or country implements its own architectures for ICT and the way they expose their services for usage is not coherent. The data formats and Ontologies used for describing the data and exchange between the various components in the ICT domain is also varied making it difficult to access the required information when needed. It is not feasible to write an application tailored to connect to each and every of these Smart City APIs and interpreting the data received. In addition, there are multiple competing standards for IoT which further makes it difficult to consume and disseminate data and connect to networks [9].

The EU H2020 IoT Crawler project in the lines of solving interoperability issues aims to enable discovery and usage of IoT devices and their capabilities through generic APIs [10]. These APIs would allow to connect and send or recall data from discovered servers or platforms. The European Committee for Standardization, the European Committee for Electrotechnical Standardization and the European Telecommunications Standards Institute (CENELEC-ETSI) Sector forum on Smart and Sustainable cities and communities is also working towards standardizing Smart City ICT technologies and frameworks [11].

4.2 Privacy and security concerns

Private users are always concerned about the data that is utilized by the applications they run on their devices. This leads to users being extra vigilant about the data that they upload knowingly or unknowingly. Some applications ask for explicit access to multiple resources on users' devices and this retracts users from using applications and disabling of certain features such as the GPS usage to report their locations. Also, applications use ports and resources on devices which can be exploited by malicious individuals. This further prevents users from using applications that are

voluntary in nature due to security concerns. Non-public agencies participating in HADR operations like the military also might not want their assets to be accessible by the civilians for security concerns.

The EU has its standards laid out for data protection and online privacy of its citizens which apply to both companies and organizations (public and private) in the EU and those based outside the EU who offer goods or services in the EU [12]. Such standards for a HADR operation can be reused or modified for accessing civilian data by multiple agencies.

4.3 Trust issues

One of the primary concerns regarding utilizing open data is: if the data received from the platforms can be trusted to be utilized. Based on the data received, the emergency responders have to take appropriate actions which require considerable resource utilization and planning. Especially in a disaster situation when the resources are already exhausted, false positives and negatives can be a serious concern.

A way to resolve this could be using methods of cooperative sensing where multiple individuals confirm the report from the affected area combined with visual inputs in the form of photos and videos.

4.4 Connectivity issues

In disaster situations like earthquakes, cyclones etc., there are possibilities of traditional means of connectivity being compromised. In addition, connectivity and computing assets acting as gateways might be compromised leading to a gap in the information flow.

Possible workarounds to restore connectivity between the existing ICT assets can be achieved through ad-hoc networks. A concept for Military Tactical Operations Center (MTOC) was proposed in [9] where a military communications vehicle could provide ad-hoc mobile LTE connectivity and provide radio transmission capabilities. In addition,

Project Name	Description and Key Concepts
<p>DRK-Retter4U App (https://www.drk-rhein-nahe.de/app.html)</p>	<ul style="list-style-type: none"> • German Red Cross Rescue App • App for private individuals and volunteers for disaster relief work • Exploits social media data related to disaster and rescue related posts • Data collection, filtering and processing using keywords, hashtags etc. • Relief services delivered based on social media content analysis.
<p>I-REACT (http://www.i-react.eu/)</p>	<ul style="list-style-type: none"> • Improving Resilience to Emergencies through Advanced Cyber Technologies • App jointly developed by UNESCO and the European Union • Shared SA between citizens by sharing geo-localized photos and information about disaster events • Information from citizens through social media platforms • Enable civil protection services and policymakers to effectively plan and act in disaster situations
<p>IRIS (https://www.cik.uni-paderborn.de/projekte/public-safety-security/iris/)</p>	<ul style="list-style-type: none"> • Intelligent Rescue in Smart Home • Research project for civilian protection from Bonn, Germany • Using the Smart Home data to assist emergency forces in disaster situations • Obtain detailed picture of an emergency situation such as fire at an early stage
<p>Smart City 3.0 (https://safesmart.city/en/smart-cities-3-0/)</p>	<ul style="list-style-type: none"> • Crowdsourcing for both government aims and integrating new technologies in cities • Citizens to define and solve problems of stakeholders and neighborhoods • Data collected and analyzed available to any requesting individual or firm • City and its citizens are owners and managers of the data • Barcelona, Rotterdam and Amsterdam as pilots

Fig. 4. Upcoming projects and initiatives for Crowdsourcing and Crowdsensing.

resources such as Google balloons for ad-hoc network connectivity deployed in Kenya could be used as fallback LTE nodes [13].

4.5 Service architecture

The service architectures of Smart City platforms are generally not designed to deal with HADR situations. The nature of the computational environment in HADR scenarios is highly dynamic, in which many concurrent services with different priorities compete for computing and bandwidth resources. For instance, emergency rescue related services will have higher priority in resource access in a HADR situation. Also, service priorities can significantly change over time and even impromptu, e.g., in case SA of a previously unexplored area becomes necessary. In such cases, the services that use and deliver Crowdsourcing and Crowdsensing data may take a backseat even though they might be essential for HADR ops.

A way to traverse around this bottleneck would be include HADR specific Crowdsourcing and Crowdsensing services that can be activated during disaster scenarios. This might include support at the middleware level for HADR specific information processing architectures.

5 PROMISING RESEARCH DIRECTIONS

The recently concluded North Atlantic Treaty Organization (NATO) Information Systems Technology Panel (IST)-147 Research Task Group (RTG) on Military Applications of IoT investigated the interoperability aspects of the IoT and Smart City domains. It analyzed issues and proposed measures to enable federation between participating military HADR agencies of various nations [9]. IST-147 studied how

to leverage Smart Cities' Crowdsourcing and Crowdsensing capabilities to assist HADR agencies by fusing military and civilian SA information. These goals will be further pursued by the newly created IST-176 RTG on Federated Interoperability of Military C2 and IoT Systems, which will succeed to IST-147 and build on its important results.

Regarding lack of standardisation in Smart City domain with respect to architectures, services and device usage, IEEE recently constituted the Smart City Working Group. The group aims at being a collaborative effort to investigate new ideas, techniques and methods for the application of IoT for Smart Cities. It will investigate standards and architectures, technology advancements, and build on the network of global professionals in this space in collaboration with many other government agencies and industry consortiums. The group is involved in proposing standardisation related technicalities and use-cases for the Smart City domain. Crowdsourcing and Crowdsensing related developments and products will be investigated during the group's tenure and would look into introducing these concepts in the Smart City's architectures during their conception.

At the information processing layer, traditional centralized solutions, based on big data analytics running in Cloud computing platforms, cannot withstand disrupted communication infrastructures and perform effective information processing using only the resources available at the edge. There is a need, instead, to consider new solutions at the service model and architecture level that accomplish this ambitious goal by exploring interesting trade-offs between processing speed and accurate/comprehensive analysis.

The processing and dissemination of all the raw data received is not possible due to limited amount of resources available at the edge and at central servers. For this purpose,

VoI based methodologies and tools, that rank information (and the corresponding services) for the value they provide to end users, represent a particularly promising research direction. Classifying each discrete element of information according to the value it provides to its recipients represents a natural and very effective criterion to discard data. Thus prioritizing analysis of novel data potentially provides a significant improvement for SA generation. In turn, ranking services and service components according to the total amount of VoI they provide to end users represent a natural and effective approach to realize self-adaptive services for Fog computing applications.

SPF is such a VoI based (as in 'Sieve, Process, and Forward') open source platform to address the issues of HADR applications in Smart Cities (<https://ds.unife.it/research/projects/spf/>). SPF advocates the adoption of an *acceptable lossiness* perspective for the realization of information processing services at the edge. More specifically, SPF service components execute on edge devices associate a VoI to each Information Object (IO) they process according to service- and data-specific metrics and policies. At each processing stage, IOs are prioritized for processing and dissemination according to their VoI, ensuring real-time operations despite the resource constraints.

Several experimentations to validate the SPF VoI-based approach for Crowdsensing applications in Smart Cities, both at the small scale real testbed [14] as well as at the larger scale simulated testbed level [15], demonstrated its effectiveness in delivering high levels of Quality-of-Service even in resource scarce environments.

In addition, one SPF-based prototype for a pilot level implementation was used during a live demonstration performed by the IST-147 RTG at the (IEEE- and NATO STO-supported) International Conference on Military Communications and Information Systems (ICMCIS 2018) in Warsaw, Poland [9]. The demonstration aimed at re-enacting a Smart City based HADR operation scenarios: it involved IoT devices and services as well as Smart City services accessed through REST APIs from the city of Warsaw, which were used in conjunction with proprietary military IoT assets. The idea was to demonstrate the interoperability between ICT systems from various domains to support emergency responders in case of disasters in the city. In the demonstration, SPF integrated with other military systems and instantiated tasks on demand for processing of data at the edge, transcoding and running image recognition algorithms on video feeds from street cameras which were consumed by military C2 applications.

The promising results obtained stimulated us in further exploring VoI based methodologies. In fact, we are currently investigating (significantly) more sophisticated VoI evaluation solutions based on an estimate of the level of interest that end users might have in a given IO, also considering the information already likely in the user's possession. Finally, we are developing an automated resource management platform that instantiates service component in edge devices by maximizing the total VoI generated.

6 CONCLUSION

Despite the formidable challenges ahead, researchers in academia, industry, and governmental agencies are working

towards developing HADR solutions that might help Smart Cities to recover from disasters in the near future. However, these solutions often leverage models and architectures that represent a significant paradigm shift with respect to the currently proposed approaches. As a result, there is still a lot of work to be done to validate them as building blocks of the next generation HADR applications.

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Manas Pradhan received his Bachelor's degree in Computer Science and Engineering from the Institute of Technical Education & Research, Bhubaneswar, India, in 2009. He worked as a Software Engineer before commencing Masters in Media Informatics from RWTH Aachen University, Aachen, Germany, ending in 2016. Since 2014, he is working as a researcher at the Fraunhofer Institute for Communication, Information

Processing and Ergonomics FKIE in the area of military interoperability, Internet-of-Things technologies and Smart Cities.

Frank T. Johnsen received the Cand. scient. degree in 2002, and the Ph.D. degree in 2010, both from the University of Oslo. He has been employed at the Norwegian Defense Research Establishment (FFI) since 2006. His research interests include distributed systems, network protocols and middleware, with a special focus on Web services technology.

Mauro Tortonesi is an assistant professor at the Department of Mathematics and Computer Science of the University of Ferrara, Italy. He co-authored over 80 papers published in international venues in the Distributed Systems research area, with particular reference to IoT solutions in industrial and military environments, Cloud and Fog Computing, wireless middleware, and IT service management. He has been a visiting scientist at the Florida Institute for Human & Machine Cognition (IHMC) in Pensacola, FL, USA in 2004-2005 and at the United States Army Research Lab in Adelphi, MD, USA in 2015. Dr. Tortonesi holds 2 international patents and participates to the Editorial Board of 4 international scholarly journals.

Sabine Delaitre received her Engineering Degree in Computer Science in 1996 and Doctorate from the Ecole des Mines de Paris, France in 2000. She is a senior R&D&I manager at Wellness Telecom with 15+ years expertise with EU-funded projects (H2020, FP7) in the field of ICT and more recently on the topics related to Big data analytics, Blockchain, IoT, Ambient Intelligence, Co-design HW/SW, and embedded software.