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# Layered Architectural Model for Collaborative Computing in Peripheral Autonomous Networks of Mobile Devices

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**Abstract**

Collaborative mobile computing is today one of the most popular paradigms of computing because of its impact on the performance and expansion of distributed systems and therefore on the development of Internet of Things. Due to the rapid progress in technologies of communication and smart mobile devices with the growing trend towards its use, many architectures of mobile collaborative computing have emerged to improve and organize the expand of Internet of Things, such as Cloud, Cloudlet, Fog, Edge, Mobile Edge, Mobile Cloudlet Computing, etc. In this paper, we first review their current layered architectural models and discuss their limits and challenges. Then, we will present a new architectural model: Collaborative Autonomous Networks of Mobile Devices Using Peer-to-Peer Communication that can be applied in many areas. Finally, a scenario of an emergency situation is presented to illustrate and highlight its requirements, such as supporting connectivity and engineering of data and services. Also, how the rescue process is addressing across different architecture layers.



*Keywords:* Smart devices, smart cities, communication technologies, communication challenges, Peer-Peer communication requirements, Mobile Collaborative Frameworks, Fog Computing, Internet of Things (IoT).

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## 1. Introduction

The rapid technological development in the fields of hardware and software for telecommunications and smart devices has necessitated the development of new communication standards adapted to resource constrained devices in various areas of energy, communication and computing capabilities.

Recently, potential efforts are being made for reducing computing costs and increasing computing power in mobile devices that experiencing many limitations. This trend has witnessed industries and academia to significantly address issues of collaborative mobile computing at the networks periphery like Fog, Edge, Mobile Cloud, Mobile Cloudlet Computing, smart multi-groups devices etc.

These technologies have differences in their architectural layers. Some of them have focused on certain structural phases, while others have found them to be unnecessary. These differences are evident as we move from centralized techniques to the periphery ones.

The objective of our study is to contribute to the improvement of collaborative computing on autonomous or individual mobile networks of smart devices connected via standard wireless or Wi-Fi Direct technologies. This to make these networks more and more efficient and smart to meet the different requirements, especially urgent needs as in the case of disasters [3]. Therefore, we designed a layered architectural of this project to ease and organize both of its building and using processes.

In this context, our project focuses on layers of task application, service engineering including two fields: computing modules and operation, data engineering consisting on formatting and unification, adaptation and connectivity that includes network infrastructure and communication.

The rest of the document contains the following sections and a conclusion: A review of IoT architecture, Related works of recent architecture models supporting Internet of Things (IoT), Limits and challenges of existing architectures Models, Overview of our project: Collaborative Autonomous Networks of Mobile Devices Using Peer-to-Peer Communication and Layered architectural of our proposed approach.

## 2. IoT Architecture Review

The IoT paradigm, as a formal and abstract general framework, has no single consensus on architecture that is universally agreed upon. Different architectures have been proposed by different researchers. The earlier one defines the main idea of the IoT which is composed of three layers [14, 13, 15]:

1) The perception layer as a physical layer, which is equipped with devices for detecting and collecting information about the environment in which it identifies other smart objects.
2) The network layer which is dedicated to connection to other objects and to the transmission and processing of devices data.
3) The application layer is responsible for providing the user by application specific services, in which IoT can be deployed, such as smart homes, smart cities and smart healthcare.

Another architecture more recent is the five layers architecture, which includes the processing and business layers additionally of the first one [14, 13–17]. The five layers are perception, transport, processing, application, and business layers. The perception and application layers have the same role as the architecture with three layers. The other layers are:

1) The transport layer transfers the data between the perception and processing layers via networks.
2) The processing layer or middleware layer stores, analyzes, and processes huge amounts of data from the transport layer. It can manage and provide a diverse set of services to the lower layers.
3) The business layer manages the entire IoT system, including applications, business and profit models, and user privacy.

Ning and Wang [14, 16] proposed another architecture inspired by the layers of processing in the human brain. It consists of three parts by analogous between (i) the human brain with the processing and data management unit or the data center, (ii) the spinal cord with the distributed network of data processing nodes and smart gateways, (iii) the network of nerves with the networking components and sensors.

A Reference Model of IoT architecture proposed by CISCO consists of 7 layers†:

1) Physical Devices & Controllers: the "Things" in IoT.
2) Connectivity: communication & processing units.
3) Edge Computing: data element analysis & transformation.
4) Data Accumulation: storage.
5) Data Abstraction: aggregation & access.
6) Application: reporting, analytics and control.
7) Collaboration & Processes: involving people & business processes.

Based on these formal and general IoT structures the main companies operating in the field of information technologies have developed their own architectures that support and reinforce the IoT paradigm. This is illustrated by the emergence of the following structures: Cloud, Fog, Edge, Mobile Cloud, Mobile Edge Computing etc.

## 3. Related works of recent approaches architecture supporting Internet of Things (IoT)

From a new perspective Azam *et al.* [21] considered that "other than sensors and IoT nodes, smartphones are also going to be part of IoT." They illustrated a combined architecture (CoT) that is composed of IoT and Cloud Computing. They declared that: "CoT will play an important role in this regard, not only in delivering the service, but also, managing it." The CoT architecture as it is an integration of "IoTs and cloud data communication", consists of three layers: IoT layer, Cloud layer and Access layer. This architecture inherits Cloud problems and it has many challenges at the levels of protocol support, energy efficiency, resource allocation, identity management, IPv6 (for identification of communicating objects) Deployment, service discovery, quality of service provisioning, location of data storage, security and privacy and communication of unnecessary data.

Aliyu, *et al.* [6] focused on five-layered architecture of Mobile Cloud Computing (MCC) including task application, perception, network infrastructure, Internet and communication, and computation layers.

The task application layer represents applications of resource consuming that includes: mobile healthcare, mobile learning, mobile commerce, mobile safety, mobile gaming and mobile social-media. This layer operates applications of: management, service management, Offloading Decision Module (ODM), service-based data management, authentication, and authorization.

Perception layer represents Mobile Devices (MDs), such as smartphones, Personal Device Assistance (PDA), IPAD, laptops, etc. The perception layer is represented at physical layer of the OSI model. It also handles the heterogeneity of MDs in terms of communication. Further, deals with physical connection of the MDs.

Network infrastructure layer represents devices that used for internetworking/routing technologies, cloudlet devices and their functionalities in MCC. The infrastructure can serve as gateway for the MCC connection offloading. These gateway devices include cellular base stations, cellular satellite, access points etc.

Internet and Communications layer handles the different internet technologies for communication between MDs and the computation layer in Cloud. It serves as a link that uses TCP, UDP and IP protocols for this communication.

Computation layer is represented by sophisticated datacenters, servers of conventional Cloud, and Task Offloading Manager (TOM) and their functionalities in MCC. It is dubbed as Cloud layer and it also consist of the CC services with no mobility.

A popular technique is presented in [5] for extending the natural capabilities of mobile devices this is Code offloading. It migrates processor-intensive tasks to resource-rich surrogates. MobiCOP is a fully functional code offloading framework of Android devices. It offers implementation of all modules expected of such a system, including a remote execution environment, a decision-making engine, and a communication layer. The offloading operation is performed via this layer by implementing a suspend-wait-resume scheme on the client and contacting, through either

† https://www.cisco.com/c/dam/global/en_ph/assets/ciscoconnect/pdf/bigdata/jim_green_cisco_connect.pdf

Wi-Fi or Bluetooth, a server deployed on another mobile device. The MobiCOP's communication layer which built with mobility in mind was designed under unreliable network conditions to minimize traffic and power consumption.

The end-to-end (E2E) network slicing is considered in [4] as a foundation to support diversified 5G services and as a key to 5G network architecture evolution. It is stated in [4] that "based on Network Functions Virtualization (NFV) and Software Defined Network (SDN), physical infrastructure of the future network architecture consists of sites and three-layer data centers (DCs) (consist of computing and storage resources). Sites support multiple modes (such as 5G, LTE, and Wi-Fi) in the form of macro, micro, and pico base stations to implement the RAN real-time function." The central DC is the bottom layer that is closest in relative proximity to the base station side. The local DC is the middle layer, and the upper layer is the regional DC, with each layer of arranged Data Centers connected through transport networks. The authors proceed with a 3D Layered Architecture of IoT that consists of the following layers: physical, network communication, processing, storage, abstraction, service, application and collaboration with processes.

A generic multi-layer is presented in [1] as the ROS-JADE Integration Architecture for the manufacturing entity in the future factories. It can be represented as an individual Cyber Physical Production System (CPPS). This work contributes to the definition of a generic multi-layer architecture for enabling the MARS (Multi-Agent Robotic Systems) social abilities in ATVs (Autonomous Transport Vehicle) and, thus, fulfilling MR1 and MR2 (MR: Main Requirement).

This architecture comprises 4 layers: social, cognitive, operative and functional. The main goal of the higher layer is to offer the services of the ROS entity to other agents in the environment. The intermediate layers are designed for efficient execution, while the inner control of the robotic device is constituted in the lowest layer. "This layer (functional) deals with the basic ATV control (sensors, actuators, robotic algorithms...) and is implemented by means of a RF (robotic framework). The intermediate layers are responsible for abstracting the social behavior from the ATV functionality and, at the same time, they oversee pre-processing and storing the information needed at the social layer for achieving fast negotiation response. Besides, these layers are also in charge of transmitting information and events between the functional and social layers. "

By leveraging Fog Computing aggregation of services as a driver for more sophisticated IoT applications, a new architecture has been developed, viz. the CoFog [2]. It is a service layer that provides ways to dynamically define and create services based on predefined templates. These services can be aggregated through formal mechanisms called operations. An operation represents a relationship between a given collaboration request and the services that can be used to fulfill that request. With mathematical formulas, a service (or more) can be composed, transformed or aggregated to dynamically create new services. There are two types of operations: conservative and non-conservative. The second type produces a new type of data. However, the first type of operation retains the same type of data. In this way, depending on the use case, a conservative operation can be applied recursively to obtain the desired results.

Aggregation services are important mechanisms in the CoFog architecture that allow it to discover and extract such services represented in a data sharing model. This model gives objects and applications connected to IoT the opportunity to discover the services offered in other Fog nodes. In the case where a Fog node is unable to provide the requested services, it transmits the request to the neighboring nodes listed in its whitelist. In this way, any nearby Fog node can be used to satisfy the request. In terms of security, two of the main access control models have been studied and extended to integrate the collaboration aspects into the CoFog architecture: role-based access control and access control models based on attributes.

The architectural Model of CoFog consists of the following layers: Adaptation, Formatting & Unification, Operation and Service where their main services as follow:

The adaptation layer provides an abstract interface with the underlying resource infrastructure. It also provides generic means for defining virtual devices and objects.

The Formatting and unification layer provide methods for describing information and data filtering mechanisms. It generates a unified and consistent view for standardizing filtered data. Also, it handles the heterogeneity of the infrastructure from a data semantic perspective.

The operations layer provides, through a combination of processes, a devices virtualization mechanism based on the request for dynamic and / or static services offered and contextual information.

The service layer provides, by leveraging the capabilities of the lower layers (such as, formatting, filtering, unification and virtualization of resources and data), a dynamic service orchestration to manage heterogeneity. In addition, it must offer an abstract and generic API to accelerate and facilitate the deployment of systems based on the Fog service.

A computational model of a multilayer architecture is described in [7]. It is dedicated for improving the performance of devices using Mobile Cloud Computing. The research described in this work presents a computational model of a multilayer architecture for increasing the performance of devices using the Mobile Cloud Computing paradigm. The main novelty of this work lies in the definition of a comprehensive model in which all the computing platforms that are available along the network layers are involved in outsourcing the application workload. It provides a generalization of the MCC (Mobile Cloud Computing) field which allows handling the complexity of scheduling tasks in such complex scenarios.

## 4. Limits and challenges of existing architectures models

IoT deals with a heterogeneous environment where the main requirements for its architecture are scalability, interoperability, openness, and modularity. This architecture should enable data analytics, easy and scalable management functionalities, cross-domain interactions, multi-systems integration, etc. There are numerous proposed IoT architecture models based on layered structures [19, 20]. But still, there is no common or general architecture which provides full interoperability.

Through a specific study of current architecture models that allowed recognition of the range of methods that support the Internet of Things, it was possible, in the one hand, to better understand the tools, techniques, and methodologies to meet the developer's requirements. And, on the other hand, to solve real life problems by building and disseminating IoT powerful concepts. These are helpful to fill gaps within the current trends of architecture to fit the exact IoT power. So, numerous studies and researches have been carried out with the aim of finding possible solutions to integrate the gap in the current architectures of the Internet of Things to be at its full potential [18].

In this context, we highlight especially the efforts needed to bridge the gap in the Internet of Things in the emerging paradigm that results from the interaction and integration of mobile devices at the peripheries of Internet networks.

Our study of IoT existing architecture models was done through the framework of the approaches that support it. This study aims to, on the one hand, improve the understanding of related tools, technologies and methodologies to meet the requirements of users and developers, and, on the other hand, fill the lacuna in current architectural trends to assess the IoT power, especially at the networks edge.

The peripheral networks suffer on several levels more than other networks located closer to the service centers. Basically, the communication with these centers is according to the number of base stations or access points to cross. Especially, since this issue has the greatest impact on most other problems of these networks such as low capacity in response time power, computing and storage. Therefore, the establishment of new architectures is required to bring services closer to peripherals, to reduce access to the main Cloud center. Thus, emerging architectures are created such as Fog, Edge, Mobile Edge, Mobile Cloud, Cloudlet, etc. These architectures, which use communication technologies based on switches, routers, gateways, and base stations, have contributed to strengthen the collaborative mobile computing and the Internet of Things. This is realized, when communication is maintained, by reducing network congestion and enhancing its connection and consequently optimizing the latency and the tasks achievement times. However, these architectures still have limitations, among others, the lack of tasks unloading to central or peripheral servers [11], the loss of user mobility in case of Cloudlet, the big number of hops (passing packets between devices, when number is greater than 2) [10], the limitation of centers resources in capacity and budget which raises a great competition between applications [9] and the dysfunction of Wi-Fi. So, what happens if the connection fails when the base stations and access points are out of service due to a disaster or if it is not offered as in rural areas? This question is illustrated in Fig. 1.

In response to this question, some approaches, as Mobile Cloudlet and Intelligent Multi-Groups architectures, are taking advantage of emerging direct communication technologies such as Wi-Fi Direct to bridge the gap in the collaborative mobile computing paradigm caused by the failure or interruption of the wireless connection based on access points or base stations. Unfortunately, these new architectures based on the principle of smart devices groups are having more problems and limitations. For example, Intelligent Multi-Groups Architecture does not have intergroup communication while Mobile Cloudlet supports two groups only. They don't unload to Cloud. Their group owners are non-replaceable [8], [12]. Their resources may be limited in computation, storage and energy more than previous architectures capacity. Managing these limited capacity resources is a critical challenge requiring considerable effort in tasks scheduling and load balancing at the applications level.

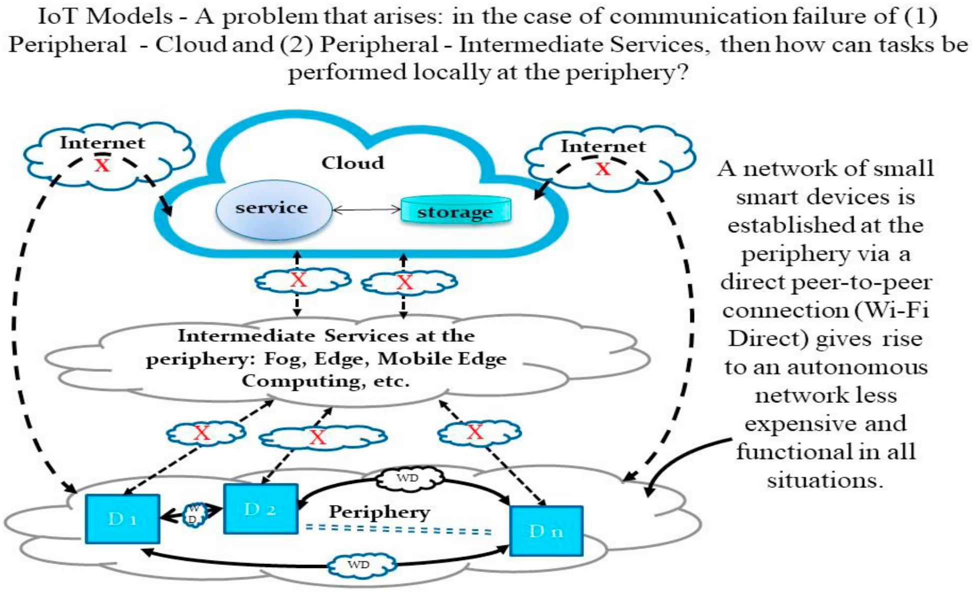


Fig. 1: Failure of Cloud and intermediate services (Emerging: Fog, Edge, …).

## 5. An overview of our project: Collaborative Autonomous Networks of Mobile Devices Using Peer-to-Peer Communication

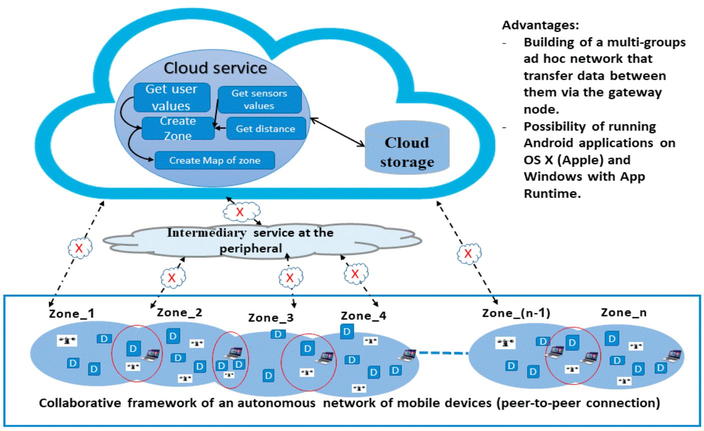


Fig. 2: Collaborative Autonomous Network Model of Mobile Devices Using Peer-to-Peer Communication.

This project (see Fig. 2) aims to perform the needed tasks in any circumstances under extreme events (e.g.: natural disasters, extreme weather, vegetation in rural areas, etc.) which can cause partial or total failures of networks and systems (in the event of disasters, Siberian attack, rural areas or failures in base stations). "This approach addresses the problems of the poor extent of the mobile network in the case of using a peer-to-peer connection. As well as, the lacuna in performing relatively large size tasks using small smart devices. This is partly due to partitioning, scheduling and distributing tasks [3]." Our approach should provide networks solutions, especially for zones on the edge of networks. These solutions will integrate Wi-Fi Direct, Wi-Fi Aware, Wi-Fi, and the Pycom Lopy4 technology to maintain and increase connectivity. In fact, where Wi-Fi Direct allows connection of intra-groups and not inter-groups, except tightly via gateway nodes between two adjacent groups, a circuit integrating Wi-Fi and Lopy4 makes it possible between group-owners for a few kilometers.

## 6. Layered architectural Model of our proposed approach

The autonomous mobile network at the edge is supposed to be a common platform supporting a wide range of application domains. This requires interoperability and resource virtualization capabilities to operate in each of these areas. In this context, our project focuses (see Fig. 3) on layers of (i) task application, (ii) service engineering including two fields: computing modules and operation, (iii) data engineering consisting on formatting and unification, (iv) adaptation and (v) connectivity that includes network infrastructure & communication.

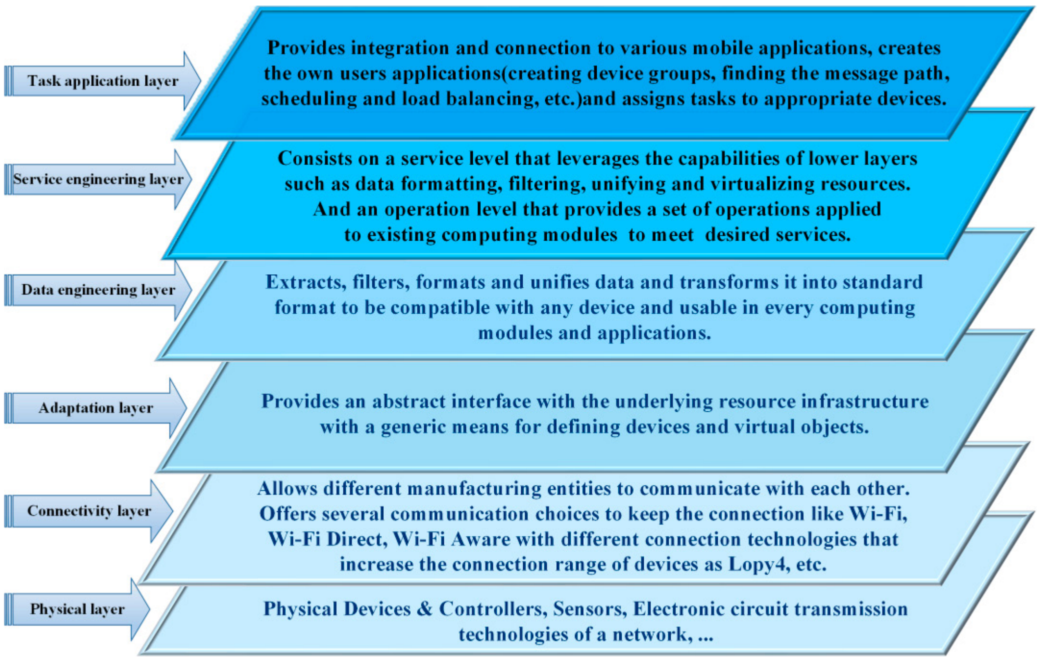


Fig. 3: Layered architectural Model of our proposed approach

i. Task application layer: The task application provides integration and connection to various mobile applications which may require significant resources for their own account. It creates user-specific applications that we need to code such as priority, security, creating device groups, finding the message path, etc. It allows tasks to be partitioned into small parts to scheduling and load balancing them on appropriate devices using other available applications.

ii. Service engineering layer: The autonomous mobile network architecture at the edge should offer a fast-lightweight service provided by computing and operational levels. It consists on leveraging lower layers functionalities such as formatting, filtering and unifying data as well as virtualizing resources. This is done by a set of operations applied to existing computing modules and operations to meet desired services.
iii. Data engineering layer: It consists of extracting, filtering, unifying and formatting data. Then, to transform data description into standard format (YAML, JSON, CSV, HDF5, etc.) to be compatible with any device and usable in every computing modules and applications.
iv. Adaptation layer: It provides an abstract interface with the underlying resource infrastructure. It provides generic means for defining devices and virtual objects.
v. Connectivity layer: It consists on the ability of different manufacturing entities (machines, robots, warehouses, operators, etc.) to communicate with each other. It offers several communication choices to keep the connection like Wi-Fi, Wi-Fi Direct, Wi-Fi Aware with different connection technologies that increases the connection range of devices like Lopy4, etc.

### *6.1. A scenario of a case study*

In a harsh environment, when the wireless internet (Wi-Fi, LTE, Lora, etc.) and cell phone connection services are shutdown, unavailable or failed, the emergency monitoring office establishes an urgent communication line, via an alternative technology such as Wi-Fi Direct, with the police, ambulance and firefighter vehicles, which are under service to evacuate an area at risk. It sends them a message containing, in addition to the necessary data captured by sensors, the latitude and longitude of this place. This to explore their paths towards this site and return to it their information as well as some sensors data. So that it can choose which of them can effectively involve in this task. This requires (see Fig. 4), on the one hand, to obtain the coordinates of this place with sensors indications and to convert them to the standard data format, then to filter the data of the drivers to choose the destinations of the messages to be sent and finally select the abstract communication interface with them. On the other hand, each driver extracts the information from the office message, reads its coordinates and the indications of the captured sensors. Then, it converts them to the standard format and chooses the appropriate application to perform the necessary calculation and afterward sends this information to the office. This requires establishing communication by means of an alternative wireless connection technology, for example, Wi-Fi Direct, Lora or Bluetooth reinforced by Lopy4.

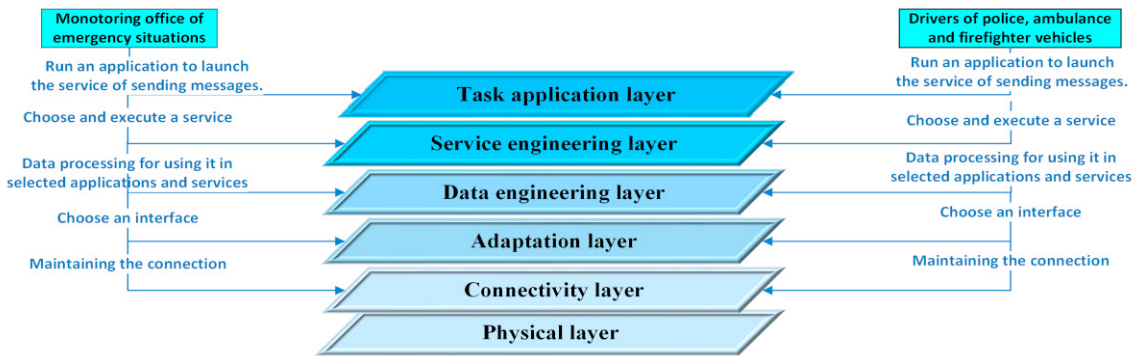


Fig. 4: A scenario of how our proposed approach works

## Conclusions

In this paper, a layered architectural design model and associated works acting in different fields of collaborative mobile computing are presented. This model can help and be applied in many areas such as smart city, smart home, police office, military management, smart parking, etc. In addition, it facilitates their realization and use.

This layered architectural design model adopts appropriate and effective communication technologies to establish and maintain the connection in extreme events and harsh environments. In this way, we presented our contribution to solve the problem of communication between different group owners in Wi-Fi Direct, as they have the same Internet Protocol (IP) addresses: 192.168.49.1. This is realized by integrating technologies such as Lopy4 into a Wi-Fi connection circuit to create our special chain of Wi-Fi hotspot; where each one is a few kilometers away from the other. In future work, many applications and services of layers in this architecture model will be developed in different areas. They are intended to establish, in the case of wireless and mobile connection failures, an autonomous network between the multi-groups of mobile devices.

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