



ROOF (REALTIME ONSITE OPERATIONS FACILITATION) COMPUTING FRAMEWORK

Authored by

Syam Madanapalli

Nishant Krishna

Shreya Solanke

Ambika P

Aishwarya Jakka

Ajay Jasti

Asesh Das

Alessio Meloni

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Steven F. Browdy

Dharam Singh

The Institute of Electrical and Electronics Engineers, Inc. 3 Park Avenue, New York, NY 10016-5997, USA

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TABLE OF CONTENTS

ABSTRACT	6
1. EXECUTIVE SUMMARY	7
2. BACKGROUND	8
2.1. HISTORY OF COMPUTER PARADIGMS	8
2.2. ADVANCEMENTS OF COMMUNICATION AND SENSOR TECHNOLOGIES.....	9
2.2.1. ADVANCEMENT IN SENSOR TECHNOLOGIES	9
2.2.2. ADVANCEMENTS IN COMMUNICATIONS	10
2.2.3. THE EVOLVING INTERNET	10
2.3. PROLIFERATIONS OF NEW APPLICATIONS.....	10
2.4. NEED FOR SPATIOTEMPORAL EVENT HANDLING REAL-TIME COMPUTING.....	11
3. THE MOTIVATION FOR ROOF COMPUTING	12
3.1. A ROOF FOR THE INTERNET OF THINGS	12
3.2. IoT AND THE AUTONOMY	12
3.3. IoT AND THE CONTEXT	13
3.4. CLOUD, FOG, IoT, AND THE MISSING BLOCK	14
3.5. THE NEW COMPUTING MODEL FOR THE INTERNET OF THINGS.....	15
4. ROOF COMPUTING	16
4.1. INTEROPERABLE CONNECTIVITY	17
4.2. CONTEXT BUILDING AND REAL-TIME DECISIONS.....	18
4.3. DATA MANAGEMENT AND EFFICIENT BACKHAUL CONNECTIVITY	19
4.4. SECURITY AND PRIVACY BY DESIGN	19
5. THE GENERAL PHILOSOPHY OF THE ROOF COMPUTING.....	20
5.1. THE ECOSYSTEM HARMONIZATION	21
5.2. WASP-WAIST CONTROL UNDER THE EDGE	21
5.3. ARCHITECTURAL SUPPORT FOR THE NEW COMPUTING MODELS	22
5.4. TARGETED DOMAINS FOR THE NEW COMPUTING MODELS	22
6. THE ROOF GOALS.....	23
7. ROOF ARCHITECTURE	23
7.1. NEED FOR AN OPEN AND EXTENSIBLE ARCHITECTURE	23
7.2. ROOF ARCHITECTURE AND EDGE COMPUTING	24
7.3. ROOF ARCHITECTURE AND TAXONOMY AND ONTOLOGY OF THE IoT KNOWLEDGE	25
8. SERVICE PROVIDER ARCHITECTURE FOR ROOF	26
9. INTERACTION OF SERVICE PROVIDERS WITH THE CORE ROOF FRAMEWORK	27
10. SCALABILITY WITH SERVICE PROVIDER MICROSERVICES ARCHITECTURE.....	28

10.1. FRAMEWORK AT THE EDGE FOR SERVICE REGISTRY, DISCOVERY, AND WORKFLOW INVOCATION	29
10.2. CARRIER FOR MACHINE LEARNING MICROMODELS AND SERVERLESS MODULES.....	31
10.3. MICROMODELS	31
10.4. ON-DEMAND DOWNLOADABLE SERVICES.....	33
10.5. EXAMPLES OF SERVICE PROVIDERS	34
11. ROOF FUNCTIONAL MODEL.....	35
11.1. INTRODUCTION	35
11.2. DETAILS ABOUT ROOF FUNCTIONAL COMPONENTS.....	37
11.2.1. THING CONNECTIVITY AND IOT SERVICES.....	37
11.2.2. ONTEXT BUILDING	37
11.2.3. CLOUD CONNECTIVITY	39
11.2.4. SECURITY	40
11.2.4.1 Secure Provisioning and Commissioning of the IoT Devices under ROOF	41
11.2.4.2 Security by Indirection.....	41
11.3. DEVICE AND NETWORK MANAGEMENT.....	42
12. APPLICATIONS AND USE CASES FOR THE ROOF	43
12.1. USE CASE—USER EXPERIENCE—MOVING FROM ONE SECURITY PROVIDER TO ANOTHER	43
12.2. USE CASE—ROOF HEALTH HUB OR ROOF MINIATURE HEALTH DATA CENTER	44
12.3. USE CASE—MONITORING PRODUCTS SHELF LIFE.....	45
13. SUMMARY.....	45
14. CITATIONS.....	46

ROOF (REALTIME ONSITE OPERATIONS FACILITATION) COMPUTING FRAMEWORK

ABSTRACT

Real-Time Operations Facilitations or ROOF is a class of computational framework for Edge Computing with Internet of Things (IoT). The ROOF framework provides supports for building scalable, secure, and robust Internet of Things applications with limited tools in resource constrained situations. The ROOF helps in developing federated architecture for large scale IoT operations. At the same time, it can provide micro-models for rapid prototyping and quick decisions making. It also provides autonomic architectural supports for spatio-temporal events handling. The ROOF framework has been designed to provide innovation, reuse, better user experience, security by design, for harmonizing horizontal as well as vertical integration for the Internet of Things ecosystem.

1. EXECUTIVE SUMMARY

The Internet has changed the way the world collaborates and shares information. It is because of the Internet that the world has become a participatory eco-system providing connectivity between humans to other living and non-living entities creating a new world, the Internet of Things (IoT). The immensely massive IoT items require intriguingly large, always evolving, billions of internet connections causing a paradigm shift in human being-and-doing. This phenomenon has made people have to think and rethink about their role in society, and how they can use these tools to advance civilization towards the brighter side of the unseen future.

Building any large-scale IoT application requires scalable and robust framework with built-in security. ROOF Computing for the Internet of Things is designed to be a framework for building large-scale, secure, and robust IoT applications. The ROOF framework is based on design patterns adapted from human evolution and the federated architecture, homes, villages/communities/cities, states, countries, and worldwide participating organizations. Each of these operates semi-autonomously and cooperates and collaborates with the next level in the federation for creating more value. ROOF Computing is a class of Edge Computing for IoT applications and provides the spatio-temporal computing needs for building context, taking actions, providing security and privacy, and providing efficient and flexible connectivity to the Cloud/Service providers. The ROOF can be implemented in IoT gateways, home routers, mobile phones, personal computing platforms, and other embedded platforms that proxy the IoT items for connectivity to the network and the Cloud.

The following are the goals in developing the ROOF Framework:

- True IoT Edge: To provide a scalable, secure, and usable framework for building IoT Edge that is always available and provides computing for real-time actions and security of IoT devices, and the data being generated and transmitted.
- Horizontalization: A framework that can be realized using the industry standards without lock-in for vendor-specific solutions thereby reducing the bar for new entrants into the IoT business and focus on their strengths to build a product or solution as part of an end-to-end IoT solution.
- Usability: To bring coherent end-user experience across the devices, technologies, vendors, service providers, and stakeholders.
- Flexible Verticalization: To provide a totally flexible framework for modifiable controls on quality of service with accelerated or truncated device use with information flows affecting desired outputs, all with decreasing risks and costs in IoT operations.

It is not the goal of the working group to produce an interoperable standard at this time. It means there can be several ways that ROOF can be implemented and achieve the previous two goals.

2. BACKGROUND

2.1. HISTORY OF COMPUTER PARADIGMS

In the mid-1970s server-based computing (FIGURE 1) was used for the timesharing of the servers among several users. As the processing speeds of the CPUs increased and the cost of computing decreased, computing shifted from servers to personal computers in the 1990s. Also, the telecom companies started offering Virtual Private Networks (VPNs) (FIGURE 2) to connect to servers in the office premises. This allowed remote computing to extend the server-based computing locations far away from the users.

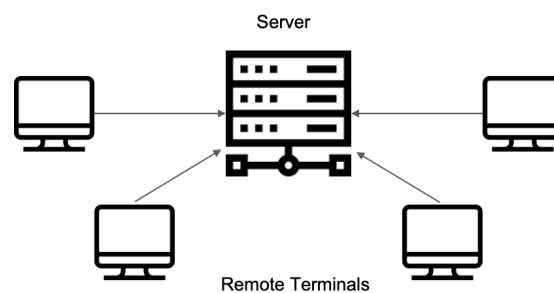


FIGURE 1 Server-based computing for time-sharing of expensive computing servers

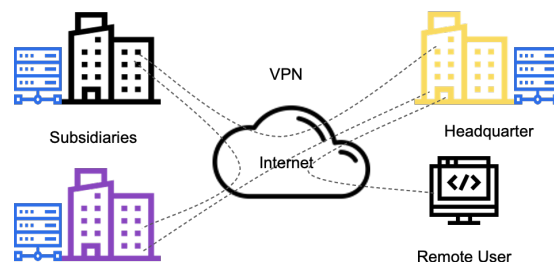


FIGURE 2 Virtual Private Networks for secure computing at the office premises

In the early 2000s, some companies including Amazon and Microsoft started offering data storage and computing power over the Internet leading to the widespread usage of Cloud-based computing (see FIGURE 3).

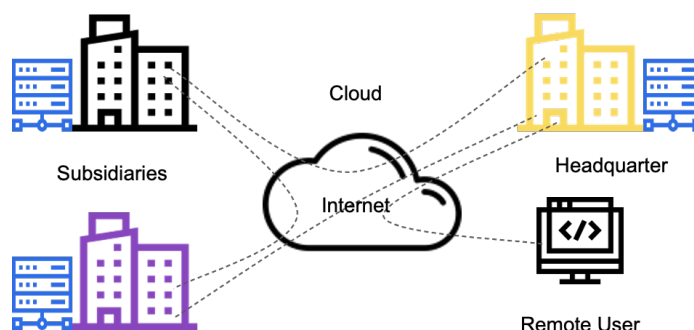


FIGURE 3 Cloud computing for service-based computing

With the advent of IoT, Cloud computing has become a more important networking element as the need for storing and processing a large amount of data has increased. However, it falls short in managing the billions of devices that have low-latency microdata transactions. Instead of forcing all processing to the Cloud, intermediary Fog computing has been proposed [1] for handling low latency tasks at the edge of the network. However, managing the Fog network, maintaining connectivity, and providing services upon that, especially in the scenarios of the Internet of Things at a large scale, is not easy. In addition, IoT devices and applications have different requirements with respect to spatiotemporal event handling for detecting and acting on anomalies, securing the devices and communication, and providing gateway functionality. Given these, Fog computing will fall under in-premise computing rather than true-IoT Edge computing.

2.2. ADVANCEMENTS OF COMMUNICATION AND SENSOR TECHNOLOGIES

2.2.1. ADVANCEMENT IN SENSOR TECHNOLOGIES

The information is built into the physical world in the form of a state that may change over a period of time. Sensors are used to measure and monitor this state information. Sensor technology, the key to any IoT application, is rapidly evolving with the advancements in electromagnetic wave, optical, acoustic, mechanical, electrical, and biological technologies while improving on reliability, sensitivity, accuracy combined with low cost. These advancements are driving the proliferation of IoT applications ranging from everyday citizen applications, such as improving comfort using a connected thermostat to advanced medical applications such as

precision minimally-invasive surgeries by robots.

As the deployment of sensors, devices, and machines increases, the ability to provide a seamless user experience in managing these devices and providing Edge computing for coherent experiences with the collaboration of the devices becomes more important.

2.2.2. ADVANCEMENTS IN COMMUNICATIONS

The communication technologies (optical and wireless technologies) are evolving to support device, human, and enterprise connectivity at varying data speeds (a few bits per second to gigabits per second) and QoS. Combining this with the growing abundance of low-power and low-cost devices allows connecting people and things over the Internet for disseminating information and collaboration.

2.2.3. THE EVOLVING INTERNET

In the 1990s, the dominant means of communication shifted from the telephone to email, and the web became the de facto standard for information sharing as the Internet became available for enterprises and residential users at affordable cost. The advent of mobile phones and the availability of broadband shifted person-to-person communication into anytime-anywhere communication. As the number of nodes being connected to the Internet increased, the IPv4 address space was getting exhausted. The Internet Engineering Task Force (IETF) developed the next-generation Internet Protocol, named IPv6. IPv6 supports 128-bit address space for a huge number of nodes to be connected to the Internet. As computing becomes cheaper and requires less power, it is possible to connect lower power and low-cost devices to the Internet giving rise to the Internet of Things.

2.3. PROLIFERATIONS OF NEW APPLICATIONS

Technology advancements are driving new applications for citizens, governments, and businesses.

- Citizens are looking for comfort, safety, security, better jobs, and better living standards
- Governments are looking for real-time governance, safety and security, better public infrastructure, and green initiatives
- Businesses are looking for improving efficiency, reducing the costs, new business models (selling function, selling outcomes), contextual AI for a competitive edge, and connected ecosystem

One of the key features that can be achieved with these advancements is the ability to build the context in real-

time and allow various stakeholders to take actions including autonomous real-time actions at the edge. To be able to provide more responsive, secure, and scalable applications, computing at the edge is critical.

2.4. NEED FOR SPATIOTEMPORAL EVENT HANDLING REAL-TIME COMPUTING

Spatiotemporal event handling requires real-time computing at a location that is closer to the physical environment. The computations for spatiotemporal event handling are performed in a pre-specified space and time (spacetime). Such a pre-specified spacetime is associated with the predictability of the outcome, context, and mission of the application.

FIGURE 4 illustrates a case with GPS working with near real-time feed from many users. An accident report was fed into the GPS system, and that caused almost or near real-time changes in original routes to other drivers. After a few miles of driving along the new route, the system may automatically report the estimated destination arrival time to the driver's home, hotel, and rental car etc.

Similar real-time (or near real-time) situations often occur in daily operations in life. For example:

- Decision making at traffic signals for cars and people, or thermostat at the home.
- Anti-lock brake systems in cars operating while skidding takes place.
- Part replenishment in manufacturing plants.
- Drinking water quality monitoring.
- Remote robot-mediated operations on the human body.
- Distributed power grids and energy distribution in emergencies.

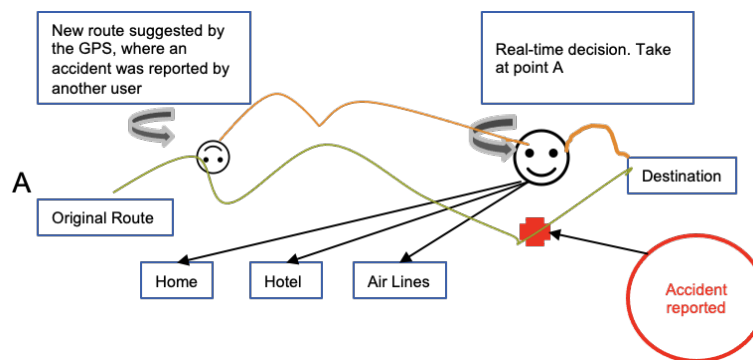


FIGURE 4 Real-time computing use case

When all the aforesaid examples and cases are present in networked communications, context development and context matching will require real-time control and real-time mediation (interoperability) to achieve guaranteed human safety, mission completeness, and running a business in complex chains of events. Moreover, when computing is done in an embedded environment, it is constrained to operate in a given pre-specified time and at that location. And for IoT, connectivity, context building, service management, and security will require hard real-time as well as near real-time computations for facilitating every IoT service desired in a society sustaining smart human living.

3. THE MOTIVATION FOR ROOF COMPUTING

3.1. A ROOF FOR THE INTERNET OF THINGS

ROOF (roof/ $\overline{\text{roof}}$, $\widetilde{\text{roof}}$ /, noun, the structure forming the upper covering of a building or vehicle) have played a significant role in human evolution, especially, providing privacy and security for the people and their possessions. In addition, people under the roof are part of a family or related, there is a trust built among them, and they live semi-autonomously within the roof and go outside to create more value, collaborate, earn, and live better. If there is a problem outside, for example, a public unrest, the people under the roof would continue to live and function and will be able to live at least for a few days without interacting with the external world.

Like humans who are weak when positioned against nature and anti-social elements, the *things* in the Internet of Things are weak when exposed over the Internet as the *things* in the IoT are constrained devices with limited capabilities and cannot protect themselves. Also, a typical IoT deployment involves multiple sensors, actuators, and/or other devices and machines, like a family under the roof, and requires a trust to be established between the things under the roof. The IoT operating within the scope that is smaller than the Cloud or the Fog requires an environment, wherein they can operate, cooperate, build trust, collaborate, and be secure.

3.2. IOT AND THE AUTONOMY

Most businesses are aggressively adopting IoT to depict what IoT is and where the value lies depending on what product or services these companies offer. The goal of any IoT deployment is to take actions: switching on sprinklers in case of fire; reacting to a broken pipe; controlling a boiler temperature as well as building more

complex contexts and taking actions in near-real-time. IoT deals with the physical world and is deployed for a mission, which requires the IoT system to function autonomously over a period of time, irrespective of what is happening elsewhere. For example, an IoT deployment in a factory should continue to function (depicted in FIGURE 5) if there is a fiber cut outside the factory disrupting the Cloud connectivity.

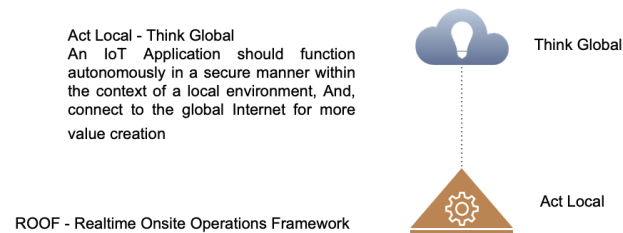


**FIGURE 5 IoT—The fundamental design goal for an IoT application:
Act Local; Think Global**

The Things in an IoT application should operate and cooperate in a secure and independent manner within the context of a local environment such as home, factory, office, or airport, etc. essentially within the context of a local environment. Each IoT deployment should be able to act autonomously over a period of time (semi-autonomous) and connect into the Fog or Cloud as needed or for an added value including data storage, large computing, information sharing, and democratization of knowledge.

3.3. IOT AND THE CONTEXT

The Internet of Things makes the environment speak for itself so that people and machines can understand the real world better. This helps in agility in making decisions and taking actions to make the world a better place to live.

IoT systems generate continuous data, which helps in building real-time context shown in FIGURE 6 as well as patterns that can be observed over a period of time. The former helps in an understanding of real-world scenarios to take actions required in real-time; the latter can be used to understand the patterns using descriptive analysis as well as to improve the scenario using predictive and prescriptive analytics. The former is real-time computing while the latter is offline computing. Offline computing is achieved using Cloud Computing, which provides a large amount of data storage as well as large data processing capacity for the analytics for more value creation for the IoT applications. However, the challenge is to provide reliable real-time computing for context building and real-time actions.

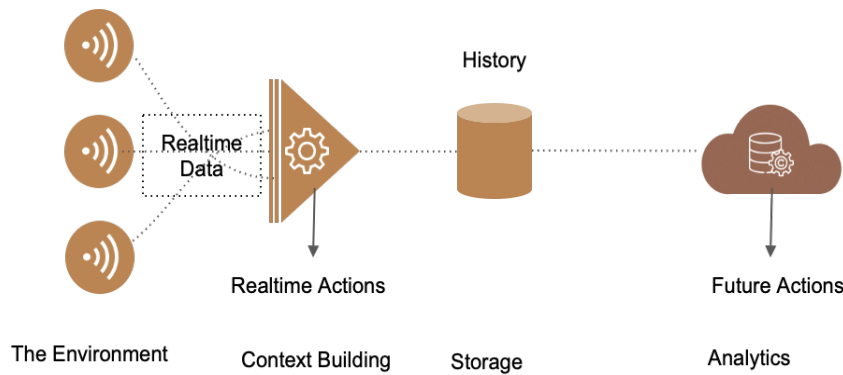


FIGURE 6 IoT and the Context Building

3.4. CLOUD, FOG, IOT, AND THE MISSING BLOCK

While the Cloud and to some extent the Fog are essential for building any large-scale IoT application, they fall short of supporting real-time computing needs for taking real-time actions and securing IoT. To support the real-time computing needs of an IoT deployment for local connectivity, real-time actions, security, and autonomous functioning, always-available Edge computing is needed. ROOF Computing is proposed as the always-available networking entity for IoT devices at the edge (see FIGURE 7).

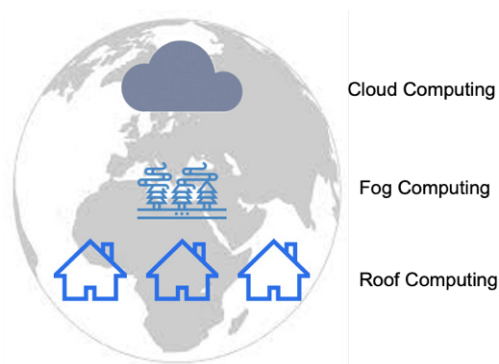


FIGURE 7 IoT, Fog, and Cloud

3.5. THE NEW COMPUTING MODEL FOR THE INTERNET OF THINGS

IoT devices are constrained devices. The following are the typical characteristics of the constrained devices:

- Limited computing power
- Low storage space
- Limited battery power
- Sporadic connectivity
- Low data rate
- A limited number of functions that they can perform
- No/minimal display and input capabilities

For the constrained devices, computing on the Cloud without intermediate computing poses the following three main challenges:

1. **Network Connectivity:** The availability of always-on connectivity to the Cloud is a challenge due to network congestion or network outage. This causes the things to be unable to send the data to the Cloud sometimes and may lose the data and commands. Implementing good coverage and reliable infrastructure to overcome this limitation might be much more expensive than the benefit of the IoT deployment.
2. **Latency:** Latency in transmitting data to the Cloud and back to the sensors might be an issue, especially, for time-sensitive applications like healthcare, emergency services, and other industrial applications. This requires the availability of computing at the next hop that is always available.
3. **Security:** Networking of things is relatively new and given that most of these Things are the constrained devices, security might not always be considered nor feasible to consider in product design.

Given these challenges, always-on computing at the Edge is required for reliable, scalable, secure, and functional IoT applications—welcome ROOF Computing.

ROOF Computing, unlike Fog Computing and Cloud Computing, is always available as the next hop for the Things and provides the spatiotemporal computing needs for building the context and required actions, security, and