Technical Report- Cloud-Robotics Research: Extending the Extended Crosschain of Blockchains (ECB) to Internet of Crosschains (IoC) and Internet of Robotics Blockchains

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Abstract: Modern consumer electronics included consumer robots, which are made by heterogeneous Internet of Things, and Internet of robotics things are integral members of the Internet of Everything (IoE). IoE plays an incumbent role in both smart cities and smart industry. Moreover, both smart city and industry IoE maintains various levels of security provisions. However, those are still vulnerable to security and privacy breaches. Nonetheless, mobility increases the risk of security and privacy breaches. As a result, in the internet era, providing seamless security and privacy for inter and intra communication of heterogeneous things is a significant challenge. Furthermore, blockchain is one of the established communication techniques that ensure both security and privacy. On the other hand, blockchain inherits trivial constraints with respect to scalability, latency, and interoperability. Cross-chain is a blockchain concept that aims to alleviate the aforementioned concerns. Therefore, we proposed a multifactor aware (privacy, security, interoperability, and scalability) model-driven reference architectures for the Internet of Crosschains is proposed for smart city and Internet of Robotics things is proposed to address issues of smart industry.

1. Introduction

Heterogeneous robots are equipped with diverse sensors, and they have been generating enormous amounts of data that have been used for diversified use cases (robots and processing requirements) involving various stages of the robotics workflows. Then, cloud computing becomes the refuge from which to address such high volumetric, velocity, and variety (3Vs) of Big Data involving robotics workflows. That implies cloud robotics (CR) and CR architecture have been playing pivotal roles in the robotics domain. Therefore, it is essential to establish an all-in-one platform for heterogeneous robotics that have wide range of data processing requirements, such as data lake (data acquisition and maintenance), and diverse requirements of processing including analytics of wide range of robots in Fukushima-RTF.

With respect to the benchmarks of Industry 4.0, autonomy and interoperability seemingly conflict with each other, and it is therefore challenging to provide both together. Moreover, interoperability may lead to creating new products and services, and drone information can be shared with weather forecasting, photogrammetry, and streaming [1]–[3]. Decentralized multi cloud (DMC) leads to an increase in the autonomy and helps to maintain the isles of each data and resource repos in a given platform. However, we should facilitate interoperability in addition to the autonomy that may reduce the quality factor of autonomy because both are inversely proportional. Blockchain is one of the leading practices in the industry that provides a solid foundation for secured interoperability as well as a single point of failure in central cloud architecture [4], [5]. However, blockchain suffers severe latency. Crosschain has been introduced to alleviate the latency concern in blockchain networks [4]–[6]. Therefore, we propose to employ a framework module for extended Crosschain of blockchains (ECB) to facilitate interoperability as well as secured autonomy.

The ECB comprises two key representations: the general public and industry. The ECB for the general public is called the Internet of Cross-chain (IoC) for Internet of Everything (IoE) in the smart city [7]. The ECB for the smart industry (SI) of the industry use case (IUC) is presented in this work. Industrial IoT essentially plays a major role in improving the process efficiency overall cost and reducing human intervention and downtime, which eventually contributes to SI of the IUC [8].

Moreover, according to our literature survey and experience on the CR domain, we learned that most of the existing CR platforms dedicate either specific use cases or domain (homogeneous) [9]. However, RTF is the place where it involves HR. Therefore, MNCRP should guarantee the privacy of each robotic use case and the security of their system to ensure integrity and robustness. For example, robots equipped with heterogeneous IoRT conduct their operation wired or wireless in CPS, FAS, and SCM. Moreover, CPS, FAS, and SCM are three of the main key components of SI. Therefore, if an intruder takes to access and controls either local or cloud communication system, it has a tremendous risk of manipulating CPS, FAS, and SCM and eventually sabotaging operations [10]. Therefore, their operation's lack of privacy and security is an enormous challenge when HR is involved in a given CR platform.

Therefore, we proposed ECB, which guarantees the following main factors: privacy, security, cross-communications, and scalability. Furthermore, Cross-chain is, a.k.a. the internet of the blockchain (IoB). Moreover, the proposed ECB dedicates the IoRT and robotics of the SI. Therefore, the proposed ECBs for SC as the Internet of Crosschains (IoC) and for SI as the Internet of Robotic Blockchains (IoRB).

2. Preliminaries and Motivation Scenarios

This section briefs the proposed RA for the MNCRP. We have detailed modelling for the RA of the MNCRP [48]. Fig. 1 shows the proposed RA.

The *physical layer*: This layer maintains heterogeneous-robots and end-users of the MNCRP. End-users described in scenario 2 dominate in this layer. All users will use same MNCRP for their heterogeneous CR requirements.

The *infrastructure layer*: This layer dominates by *CR-Eco-Sys*. The *CR-Eco-Sys* comprises collection of framework modules. Those are compelling to accomplish dedicated jobs and those are defined in *semi-formal* manner. *DMC, GD-HDFS, MUT, COE, ECB, MAA-FE, MAA-ME, DTMS,* and *ISOW* are respective framework modules proposed in the *CR-Eco-Sys*.

The *analytical layer:* This layer is responsible operations of *MAA-BE*. The *ASC* is responsible to automate all data science related workflows involving the analytics in the MNCRP.

The *DMC:* This is responsible to maintains the decentralized CR eco system of the MNCRP. The *DMC* comprises edge, fog and central-cloud as three main sub-components.

The *GD HDFS:* This component maintains fault tolerant geo-distributed Hadoop distributed file system facility. That provide provisions for cost effective (due commodity hardware, filesystem shares the hardware with the computation framework as well), scalable, resilient to failure (bounce back effectively) and fault tolerance (operating without interruption) data management.

The *MUT:* This component responsible to adapt required utility middleware technologies including ROS and tools involving CR to the *GD-HDFS* environment.

The *COE:* This component responsible to manage scalability of end-user's custom environments (container orchestration) across the geo-distributed DMC environments.

The *MAA:* This responsible to manages automation ability across the platform. As a summary, it will act as interface agent and take intelligent decisions. To ease the operational and characteristics of the overall process, we have divided *MAA* module in to three sub-components. The front-end operation of the *MAA* manages by the *MAA-FE agent,* the middle-end operation manages by the *MAA-ME agent* and the back-end operation manages by the *MAA-BE agent.* The *MAA-FE* responsible to deal with all requests are coming from the *physical layer*. Moreover, it activates adequate waypoint of the *MAA-FE agent* and drives that request to adequate waypoint of the

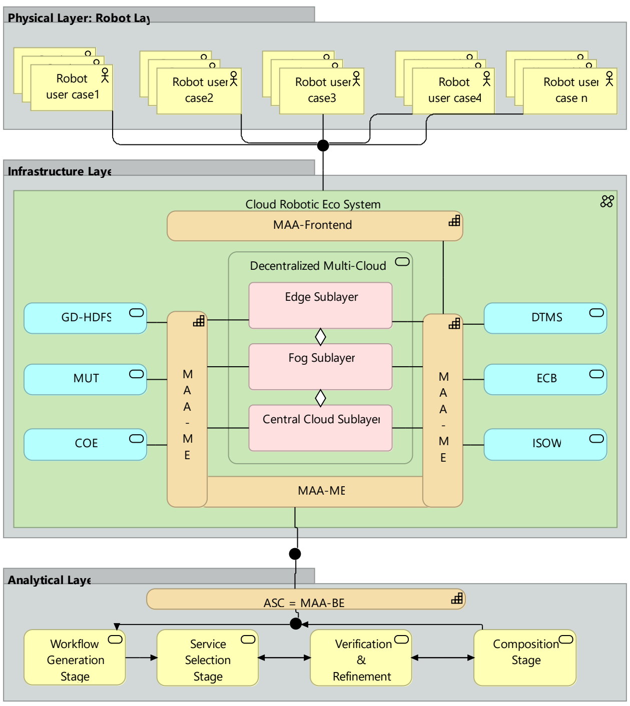


Fig. 1. M_4^{CR} Abstract normative-view - RA for framework for MNCRP

DTMS = Digital twin modeling and simulation, DMC = Decentralized multicloud,
MUT = Middleware for adapting utility technologies, COE = Container orchestration engine,
GD-HDFS = Geo-distributed Hadoop distributed file system, ECB = Extended crosschain for blockchain,
ISOW = Information as service based on domain ontology and web services
MAA = Multiagent for automation, (FE/ ME/ BE = frontend/ middle end/ backend) ASC = Automatic service composition

middle-agent. The *MAA-ME* is responsible to automatically manages that given task across the components with respective to their request's inputs and outputs. Then *MAA- BE* is responsible to automate required analytical and data science requirements (Big Data analytics, deep learning, or machine learning) if it requested such requirement by the *MAA-ME*.

The *DTMS:* This component is responsible for digital twin in the MNCRP. It allows users to prepare digital models of physical materials and robots, simulate and analyze them.

The *ECB*: This component guarantees the secured cross communication within components (intra) and systems (inter). It employs extended Crosschain of the Blockchain technology.

Scenario-1 for Smart City

Scenario 1: The University of Aizu and Fukushima prefectural government are partners of RTF, and they commenced a project to build a model smart city for next-generation Japan based on city A, which complies with Society 5.0 as one of their visionary project milestones. As a result, the robot research group at the University of Aizu will design, develop, and commission software solutions for a model smart city. DMC serves as the model smart city's cloud platform. According to a survey of city dwellers, the research team discovered that a typical family and their IoE involvement are depicted in Fig. 2, and that they have serious security and privacy concerns.

Moreover, the team identified two main types of household IoT and IoRT: fixed to a home network and portable. Nevertheless, those are dedicated to either shared or personal. Here P person and his family are shown as the representative family of city A. P person travels through Fig. 2.a, Fig. 2.b, Fig. 2.c, and Fig. 2.d subnetworks to travel to the office. He uses his office network for his portable devices. He occasionally moves to Fig. 2.e, shown as café network. He returns home via the path shown by arrows.

Providing seamless security and privacy in smart city proposals is a huge challenge. The proposed solution should, however, support scalability (end-users and their IoE).

Scenario-2 for Smart Industry

Scenario 2: Company A is designing, assembling, and maintaining FAS included CPS. *Company R* is an online automated grocery factory chain, which is already discussed in Subsection II of our previous work [3]. Fig. 3 depicts the use case of FAS deployments done by Company A. Fig. 3.a shows geo-distributed factories connected to the DMC. Fig. 3.b represents one of the factories among the SCM of *Company R*. Factory is made by multiple production lines given by Fig. 3.c. Also, in Fig. 3.c, the production line comprised a collection of cells. Fig. 3.d shows individual cells and associate CPS. Finally, fig. 3.e offers the array of IoRT involving preparing robotic arms and their operations called a cell. Meantime, *Company R* is experiencing two issues; the first issue is the risk of breaching their local and geo-distributed network by intruders. The second issue is that it has experienced a lack of confidence in the quality of service of existing SCM. Therefore, *Company A* contacts the *UoA CR research group* to find a solution for the issues mentioned above; the integrity of their SCM, privacy, and security of their communication/ operations should be addressed.

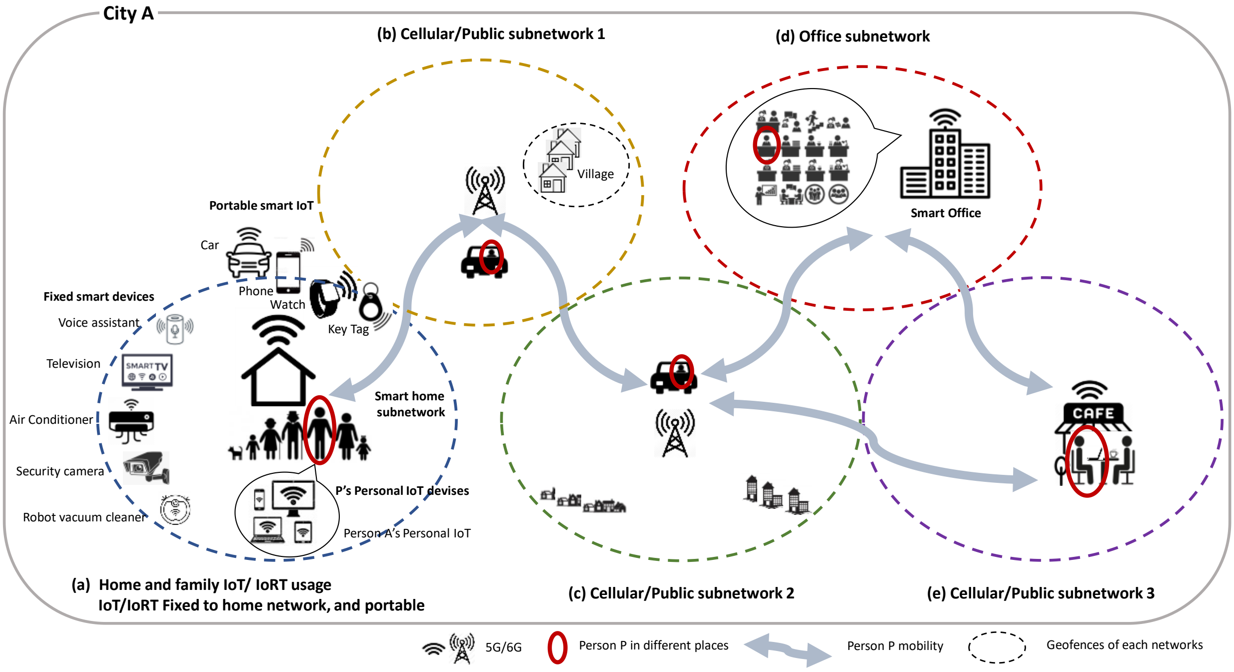
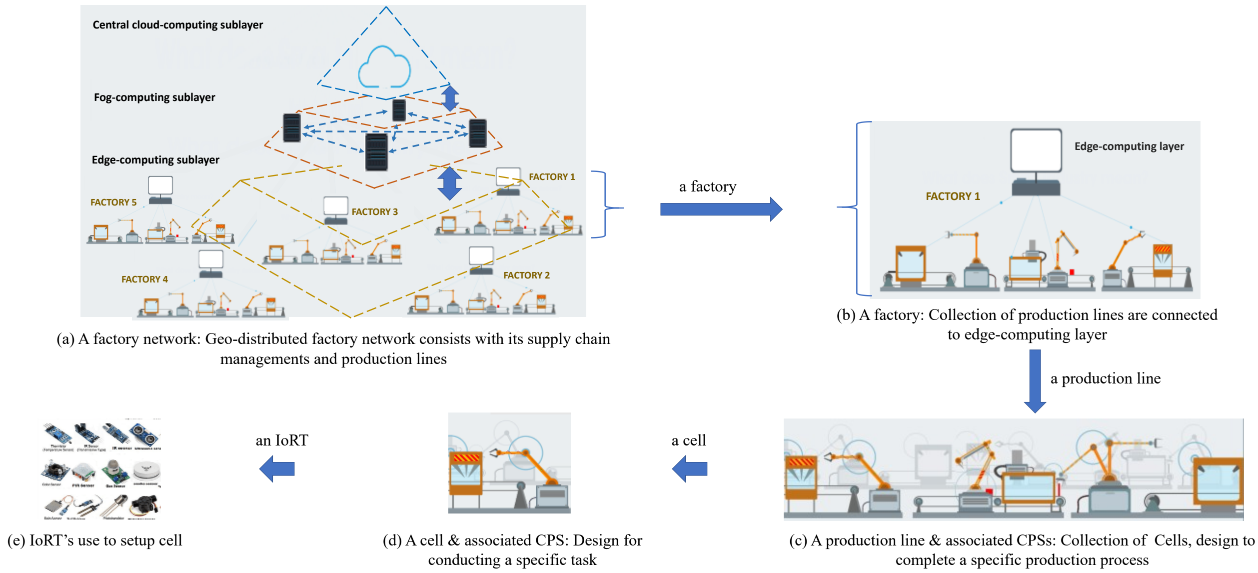


Fig. 2. City A, P person (a city dweller), his family, their IoT/IoRT usages, and person P's typical working day mobility within city subnetworks



(a) A factory network: Geo-distributed factory network consists with its supply chain managements and production lines

(b) A factory: Collection of production lines are connected to edge-computing layer

(c) A production line & associated CPSs: Collection of Cells, design to complete a specific production process

(d) A cell & associated CPS: Design for conducting a specific task

(e) IoRT's use to setup cell

Fig. 3: High level view of smart industry of smart factory network, which included factory automation system and supply chain management

3. Proposed Solutions

This section briefs the proposed RA for the MNCRP. We have detailed modelling for the RA of the MNCRP [48]. Fig. 1 shows the proposed RA.

System architecture for smart city

The derived SA for smart city A is shown in Fig. 4, which is divided into five subfigures. The smallest IoT/IoRT network is shown in Fig. 5, which was created using the Lightning blockchain. Moreover, Fig. 5.a and Fig. 5.b can be considered the IoE network's atomic representation. Fig. 4 and Fig. 5 are prepared based on Eqs. (3′.c.1) and (3′.c.2). Fig. 4 and Fig. 5 have two representations from two perspectives: physical representation (PR) and blockchain representation (BR). The physical representation or appearance of a system or its components is referred to as PR. Furthermore, for the given system or components, BR stands for blockchain terminology.

SA for the *smart city A* proposed based on *scenario 1* explained typical family and mobility. *Person A's* family is referred to, and his mobility is described in relation to him and his typical working day. Fig. 4 depicts the city's five subnetworks and their geofences. The PR of Fig. 4.a depicts *person A's* home and his family's IoT/IoRT communication network. Each adult maintains their IoT/IoRT network w.r.t. the PR and atomic blockchain w.r.t. the BR. All shared/common IoT and IoRT devices are classified into

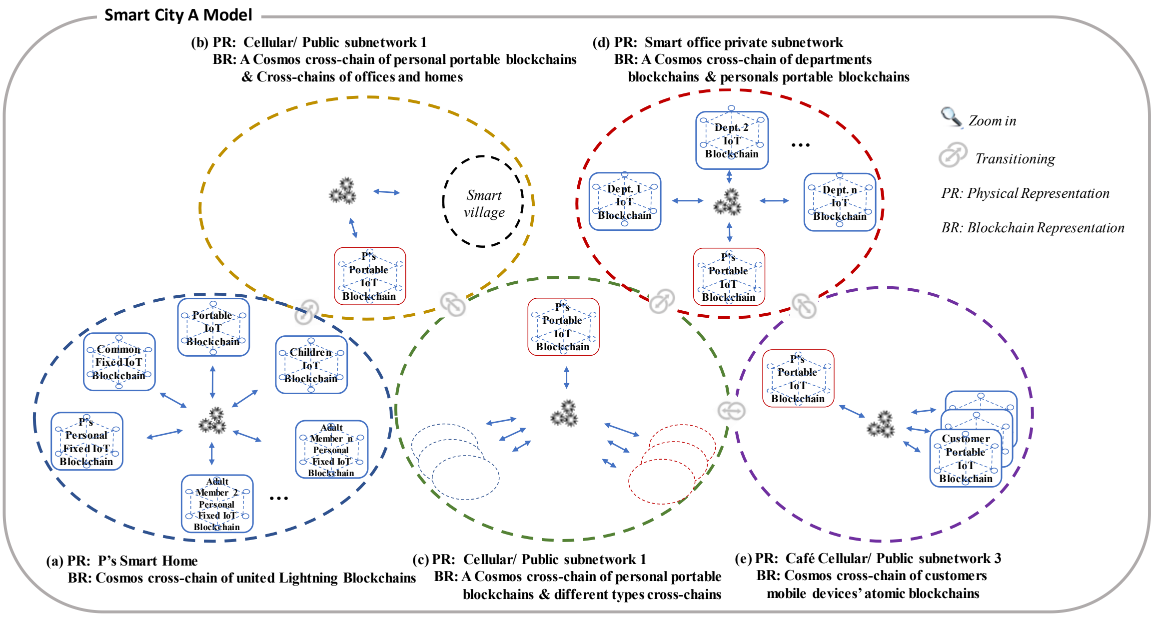


Fig. 4: M_4^{SC} abstract non-normative-view—SA for smart city A scenario 1

single or multiple subnetworks w.r.t. the PR and atomic blockchains w.r.t. the BR.

Meanwhile, according to the adult's choice, children's devices are assigned to a single or multiple subnetwork. In addition, mobile/portable devices are classified as an atomic blockchain unit. Finally, all of person A's family's atomic blockchains are linked to a single Cosmos cross-chain, which is made up of a collection of blockchains.

Fig. 4.b represents the adjacent cellular/public subnetwork w.r.t. the PR and Cosmos cross-chain w.r.t. the BR, which provides service coverage to the smart village and all mobile IoT/IoRT carriers within its geofence. Once *person A* leaves his home geofence, he enters Fig. 4.b subnetwork coverage. Then, his mobile/portable devices are transitioning into a Fig. 5 shown atomic blockchain. PR of Fig. 5.a represents *person A's* mobile device network. BR of Fig. 5.a is atomic blockchains made by IoT/IoRT.

Person A and his mobile/portable devices also traverse Fig. 4.b and Fig. 4.c subnetworks to reach Fig. 4.d subnetwork of his office. In the office environment, his office IoT/IoRT belongs by default to the respective department blockchain. Fig. 4.d office maintains Cosmos cross-chain. Moreover, *person A's* personal mobile IoT/IoRT connects office Cosmos cross-chain as an atomic blockchain shown in Fig. 5.a. When *person A* goes to the café public subnetwork shown in Fig. 4.e, the same thing happens. All mobile IoT and IoRT customers connect to the café Cosmos cross-chain via their atomic blockchains. Subsequently, we derived the SA for SI.

5. Conclusion

We proposed ECB for the smart city and industry, which is multifactor aware (security, privacy, scalability, and cross-communication) communication platforms. First, we proposed an architectural decision model, then a reasoning abstraction solution for RA, and finally devised SA's for scenarios. DMC is the IoC/CaaS cloud platform. This work is a submodule of ECB, which is one of the main modules of the MNCRP. In addition to that, prime objective of Society 5.0 is to balance economic advancement with the resolution of social problems and restore a human-centric society and its values. Cross-sectional knowledge sharing, cooperation, and reforming ecosystems are three major provisions of Society 5.0. The proposed IoC is complying with the norms set by Society 5.0.

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