Phone of Things (PoT)

Empowering IoT Systems Through the Ubiquitous Telephone Network Infrastructure and Voice Commands

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***Abstract*—This paper introduces the concept of Phone of Things (PoT), a novel approach to extend the connectivity options for IoT systems through the pervasive telephone network infrastructure. This is a paradigm shift that integrates traditional telephones to monitor and control IoT-enabled devices via VoIP protocols and public switched telephone network (PSTN). This integration democratizes IoT through the promotion of a Do-It-Yourself (DIY) IoT system that takes advantage of the freedom the comes with open-source technologies and leverages the emerging cloud-hosted services to build customized IoT solutions while accentuating affordability, accessibility, performance, ease of use, and security. Nevertheless, the proposed system inhibits a modular design philosophy that allows the system to be tailored and scaled according to the application needs with minimum hardware and software modification requirements. The proposed paradigm provides an arbitrarily shared data space between IoT systems which would coalesce into a social network of things (SNT) and support assistive services in public sensing.**

***Index Terms*—Phone of Things (PoT), Internet of Things (IoT), Voice over Internet Protocol (VoIP), Public Switched Telephone Network (PSTN), Asterisk.**

I. Introduction

The Internet of Things (IoT) became a dominant paradigm in recent years and found applications in almost every walk of life such as smart homes, smart cities, smart retail, smart vehicles, health care, and agriculture, just to cite the most appealing domains. It is actively and progressively influencing our lifestyle and helping us to make better decisions based on the information inferred from the surroundings. Estimations projected 26 billion IoT devices to be in use by 2020 compared to 0.9 billion in 2009 [1]. IoT enables effective data exchange between connected objects/devices to support decision making [2]. As the name implies, IoT is basically dependent on the Internet to provide connectivity among things. Therefore, things that constitute an IoT network essentially employ TCP/IP stack in their embedded firmware. However, simple objects with processing and/or power consumption constraints that cannot implement the TCP/IP stack can still be connected to the Internet through the use of an IoT gateway [3, 4]. One of the main challenges to IoT is the lack of interoperability between different IoT systems [5]. IoT is in fact an assortment of "*Intranet of Things*", also referred to as "*vertical silos*", from different vendors that employ different protocols and standards [6, 7]. This diversity in the underlying IoT ecosystem prohibits seamless integration between heterogeneous systems, which is a key reason that prevents IoT from reaching its potential widespread adoption [5]. Furthermore, the common risks associated when connecting IoT gadgets to the Internet also make users reluctant to connect their systems to the Internet and provide hackers a chance to exploit these intrinsically poorly-secured gadgets to penetrate the underlying critical network infrastructure. This cybersecurity anxiety prevents the utilization of a huge amount of sensed information to its maximum.

On the other hand, Voice over Internet Protocol (VoIP) is a relatively mature technology that began in 1973 when a protocol for ARPANET was invented to enable network voice [8]. However, it was not until 1995 when the first commercial VoIP solution hit the market [8]. In the beginning, the adaptation to VoIP technology seemed to be slow; from less than 1% of all business calls in 1998 to 25% in 2003 [9]. However, due to the advancement of digital transformation and the emergence of broadband technologies in the past decade, the use of VoIP is currently prevailing and reaching new heights as a reliable and cost-effective means for telecommunication over the Internet. For example, there were more than one billion mobile VoIP users in 2017, with an estimate of three billion mobile VoIP users by 2021 [9].

Alongside, with the recent advancement in Natural Language Processing (NLP), a subdomain of Artificial Intelligence (AI), chatbots are witnessing a rapid increase in use [10]. Chatbots are mainly intended to engage customers in a natural and intelligent conversational experience using a piece of software that can mimic a human agent and respond to customers' inquiries quickly and efficiently anytime and anywhere. According to [11], chatbots are occupying 39% of total chats. Besides, it estimates that 80% of organizations are planning to employ chatbots by 2020, with an estimation that 75% to 90% of customers' issues will be handled by chatbots by 2022 [12, 13]. Optimistic revenues of chatbots intrigue large technology companies like Google, Amazon, and Apple to launch their conversational experience framework for building chatbot agents. For example, Google launched Dialogflow for developing conversational interfaces [14]. Dialogflow users leverage the use of Google's world-class AI assets and capabilities, which results in faster implementation with multiple options to connect with backend systems which consequently results in better user engagement and faster time to market.

Today, more IoT devices are increasingly emerging and

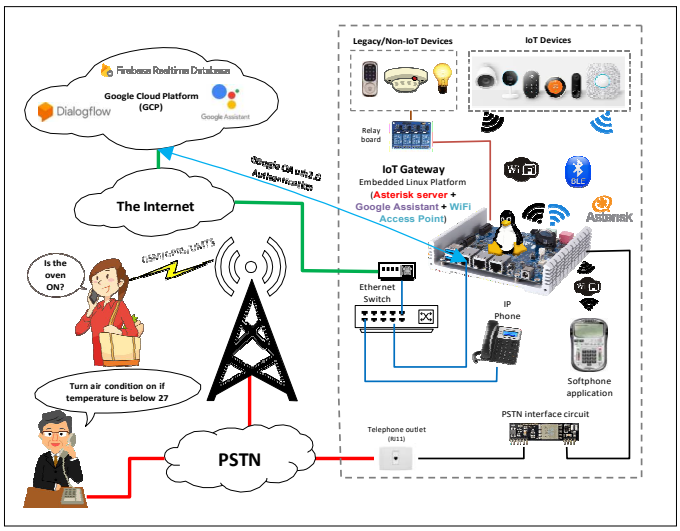


Fig. 1: PoT: Overview of the proposed system.

more companies have switched to VoIP and are employing their chatbot agents. We aim in this paper to integrate IoT, VoIP, and chatbot in a new paradigm to enhance connectivity, accessibility, and interoperability of IoT systems. At this juncture, the current state is that companies are still either using the legacy telephony system or just updated their telephony system to VoIP. However, in either case, people just still use the telephony system for the conventional voice communication between parties. However, IoT could provide new promising opportunities with a new upside for VoIP users. VoIP can serve as a part of the IoT architecture to enhance connectivity, security, automation, and monitoring capabilities. Therefore, even if there is no Internet access, the system could still function and be accessible, commanded, and monitored using a simple phone call. Moreover, alongside chatbot employment, this would furtherly enhance the IoT system accessibility with modern modality. IoT gadgets can be dealt with as a typical SIP (Session Initiation Protocol) endpoint. Each IoT gadget can then be registered to the existing unified communication (UC) solution within the premise, assigned a unique phone number, commanded using a phone call, and interacted naturally using intuitive spoken commands and vocal responses. The accessibility alone of the proposed system worth considering. It also provides a far-reaching opportunity to enable elderly, physically, and visually impaired individuals to interact with state-of-the-art products naturally without clicks or complicated graphical user interfaces (GUIs). Nonetheless, the integration of the aforementioned technologies would furtherly drive the development of smarter homes, smarter offices, and smarter telephony solutions.

The proposed scenario, depicted in Fig.1, harnesses the power of open-source technologies and cloud computing facilities to build a prototype model of a multi-tier and VoIP-enabled DIY IoT system that embodies the vision of PoT and accomplishes its designated objectives. The use case scenario targets home automation applications. However, thanks to the modular philosophy on which the proposed system is built up, the system can be tailored to fit other application needs as discussed later in Section IV.

The rest of the paper is organized as follows. Section II highlights related background of the enabling technologies employed by the concept of PoT and provides a brief overview on related work. Section III details the use case scenario of PoT in home automation application to demonstrate its feasibility and usability. Section IV discusses tweaks to the proposed use case scenario to target other IoT applications. Lastly, section V concludes the paper.

II. Background and Related Work

A. Internet of Things (IoT)

IoT is changing our lifestyle and it extends the Internet connectivity beyond just regular computers and smartphones to include everything from household appliances to industrial gadgets – each of which can transmit a plethora of sensed information and other useful data to help make better-informed business decisions. The term "*Massive IoT*" has recently emerged to reflect the rapid increase in IoT devices [15]. New technologies try to tackle the challenges related to massive IoT. For example, the fifth generation of cellular technology, denoted by 5G, is concerned about providing higher connection density. It is expected to provide a connection density of up to 1 million IoT gadgets per kilometer squared, in contrast with around 2000 IoT gadgets per kilometer squared in the current 4G [16]. It is estimated that there would be 10.9 networked devices per person in Canada by 2023 compared to 6.6 networked devices per person in 2018 [17].

Nevertheless, IoT did not still reach its potential promise. The main problems that stem from the promise of IoT are: (1) *ecosystems*: while many IoT vendors are competing in establishing a foothold in the IoT market, they are providing their own ecosystems. Regrettably, most of the underlying protocols and standards of these ecosystems are not compatible with each other. This results in the problem that there is no "*lingua franca*" spoken by each and every IoT system which hinders their interoperability [5]. IoT integrators estimate that support for some of the underlying services of these ecosystems can take up to several months, not to mention the time and effort required to maintain support for every service [18]. The interoperability problem of IoT is realized by organizations. As a result, consortia and initiatives started to emerge to allow for interoperable standards; such as the *Web of Things* initiative by W3C [19], the *Alliance for Internet of Things Innovation (AIOTI)* by the EU [20], and the *Open Platform 3.0*^{TM} at the Open Group [21], (2) *Walled off data*: despite the huge amount of sensed information gathered by the currently available IoT systems, they are considered "*walled gardens*" that are only accessible by their originators. This impedes the utilization of this information to its maximum, (3) *Cloud attacks*: since the cloud is likely the only candidate to ingest the huge amount of sensed information by IoT systems, cloud providers will be a principal target to cyberattacks. This puts system designers in a trade-off between the facilities and

the ease-of-access the cloud computing could provide to IoT systems and the panic about critical data leakage in case of a successful cyberattack, (4) *Botnet attack*: the huge amount of IoT gadgets connected to the Internet provides a wide attack surface to hackers. Actually, hackers exploit the limited-processing and poorly-protected IoT devices to penetrate the underlying critical infrastructure. One of the biggest security challenges is the distributed denial of service (DDoS) attacks [22]. IoT botnets can direct swarms of false network traffic to the poorly-protected IoT devices to cause unpredictable spikes in the underlying principal network infrastructure to reduce its availability, (5) *Device loads and bandwidth*: device loads and bandwidth limitations are other challenges that impede the widespread of IoT. This puts system designers in a trade-off between implemented device capabilities on one hand and the expected cost, power consumption, and bandwidth requirements on the other hand. Some solutions are emerged to alleviate the dependency on cloud computing and hence reducing the bandwidth and the processing power requirements like TinyML [23].

To tackle the cybersecurity risks that arise when connecting IoT devices to the Internet, this paper introduces a new dimension for IoT system connectivity using the ubiquitous telephone network infrastructure. Basically, the IP addresses of the devices connected to the Internet are assigned by the Internet service providers (ISPs). These addresses are dynamic by default; since that is more practical regarding the ISP's perspective and more cost-effective regarding the end user's perspective. The problem with these intrinsically dynamic IP addresses, that results in most of the cybersecurity attacks, is that users do not have unique addresses (identifiers) when they connect to the Internet. Moreover, these IP addresses can be easily masqueraded or spoofed using plenty of freely reachable technologies over the Internet which hardens the employment of access control restriction of remote users trying to log into the system. On the other hand, however, all phone numbers are intrinsically and globally unique. Besides, it is hard, or even impossible, to conceive a calling phone number. This provides a great opportunity for IoT system administrators to apply a finely-grained access control list to their IoT systems that is based on the phone number of the calling party which cannot be easily broken.

Besides, the proposed system provides a paradigm of a cloud-hosted database that maintains information about all connected devices to the system. This information is continuously updated on a real-time basis. The purpose of this database is to overcome the *Walled off data* problem by providing indirect access to the sensed information by the system that can be arbitrarily shared with other users and/or services that might benefit from it to make better-informed decisions. Moreover, this information can also be queried using chatbots to widen its accessibility to the maximum. This widely accessible information can then be eventually coalesced into a social network of things (SNT) and help in performing public sensing.

B. Asterisk: The Open-Source PBX

Voice over Internet Protocol (VoIP) represents a set of dedicated software and/or hardware that enables the transmission of analog voice signals over TCP/IP network (i.e. the Internet) [24]. It enables the use of any TCP/IP network as the transmission medium for telephone calls by first encapsulating voice signals into packets and then transmitting them over TCP/IP network rather than by the traditional circuit switching of the PSTN, sometimes called *plain old telephone service (POTS)*. Employing the same underlying networking infrastructure, VoIP and data communication can then be traversed over the same IP-based network. This allows to dispense the traditional telephone network infrastructure within the premises, and hence reducing both the installation and maintenance costs. Besides, telephone calls over the Internet are almost cost-free, since individuals and enterprises would not pay more than their regular Internet connection fees. As a result, large enterprises can leverage the use of the Internet to make phone calls to all their remote branches with no additional costs. Nonetheless, VoIP will soon be replacing Integrated Services Digital Network (ISDN) and the POTS, since most telecommunication companies are planning to update their legacy telephone systems to VoIP by the end of 2025 [25].

Asterisk is an open-source and Linux-based framework for building feature-rich telephony applications [26]. It is a hybrid Time Division Multiplexing (TDM) and packet voice PBX. Asterisk powers IP PBX systems, VoIP gateways, conference servers, and other custom solutions. According to statistics published by Asterisk, there are more than one million Asterisk server deployments in 170 countries, with more than 2 million annual downloads. One of the key strengths of Asterisk is the enthusiastic community members that support it. A typical Asterisk system consists of different loadable modules, each of which is responsible for specific functionality, with complex relationships between the modules. Nevertheless, the important modules for a basic functioning Asterisk PBX include the *application modules* which encompass the dialplan functions that define how calls path through the system, the *channel driver modules* which define supported interfaces to the system and act as gateways to the Asterisk core, and the *codec translator modules* which are responsible for the conversion of audio streams from one format to another [27]. In contrast to conventional PBX, the dialplan module in Asterisk is fully customizable and can be tailored to respond to external events, which is the key characteristic behind the motivation of integrating it into IoT applications. Nevertheless, although Asterisk has its scripting language to configure its operation, it can still be programmed through the use of Asterisk Gateway Interface (AGI) using famous high-level programming languages such as Python, Perl, Java, C++, PHP, and Node.js.

Asterisk can be installed on Linux-based platforms using the operating system's package manager. Most Linux distributions, such as CentOS, Ubuntu, and Fedora, encompass Asterisk packages at their repositories [27]. Nevertheless, for a fully

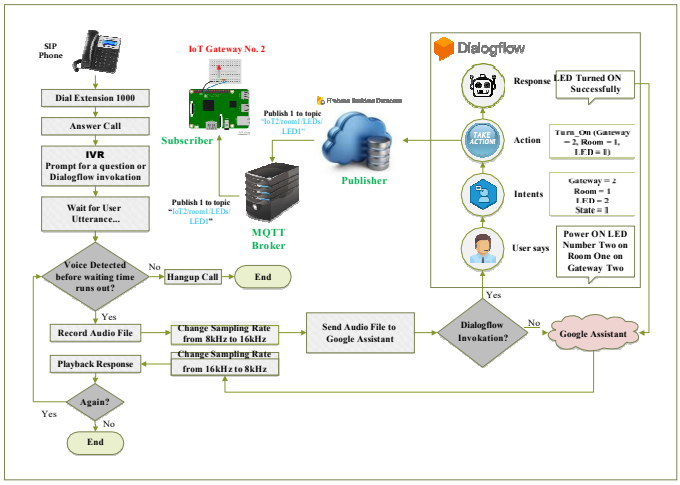


Fig. 2: Flowchart of the Integration between Asterisk and Google Assistant.

customizable installation of Asterisk, it is better to be installed from its source. On the other hand, Asterisk can be installed on a dedicated server using a pre-built Asterisk image which features a fully-fledged Asterisk system with a GUI along with the operating system. Famous open-source unified communication platforms that employ Asterisk are FreePBX, Elastix, and FreeSWITCH. Furthermore, Asterisk can also be installed on embedded Linux platforms, such as Raspberry Pi and BeagleBone Black, which intrigues the exploration of potential applications that could benefit from Asterisk integration.

To the best of our knowledge, the concept of a multi-tier IoT system that leverages the use of open-source technologies, third-party services, and the newly emerging cloud-hosting capabilities is relatively new. Phone of Things (PoT) is a novel paradigm that provides unique extensions to IoT with wider connectivity options, modularity, scalability, and potential for future upgrades to satisfy custom application needs. To the best of our knowledge, the authors of [28] were the first to enable IoT devices with SIP-based communication, named ”CoSIP”. The author of [29] proposes a system that integrates IoT with VoIP. He used similar underlying hardware to that used in this paper with the same concept of IoT gateway. However, the system is confined to the local network. Besides, it lacks voice recognition and cloud-storage capabilities. It also does not provide for scalability since the author does not offer a solution for interconnectivity and interoperability between the gateways, share of sensed information among them, and how to mitigate expected device load as the system scales up. The authors of [30] propose a SIP-based IoT gateway that automatically calls healthcare providers in case of medical emergencies based on outlier readings of biomedical sensors attached to a human. Here, the IoT gateway does not employ a SIP-server itself, but rather, it relies on an external SIP client that is responsible for initiating an emergency call to the appropriate healthcare destination, which limits its capability. The latter is an application-specific integration between IoT and VoIP. Since there is no VoIP server incorporated within the IoT gateway, it is stripped from most of the potential VoIP functionalities. In [31], the authors propose a smart water heating system for buildings that is based on IoT technology and is activated through the use of IVR (interactive voice response) on a cloud-hosted Asterisk-based PBX. Once again, this proposed system employs limited functionalities of VoIP connectivity. It neither provides for voice recognition nor allows for scalability. In [32], the authors mediated an external Asterisk PBX server as a bridge between the user and an ESP32 to control its pins using textual command inputs that are issued using a SIP client. The system lacks scalability since the authors do not provide an identification scheme to be able to control a farm of ESP32 and share data among them. Similar to the latter, the authors in [33] provide a similar approach to supervise home appliances by employing a dedicated Asterisk server and using WLAN which confined the system usage to the local home network. An interesting application of VoIP integration with an IoT system is introduced in [34]. Here, the authors tried to build a smart postbox system that auto-notifies the user by a phone call when a shipment arrives. Besides, the system allows the user to remotely inspect and open his/her postbox. However, the system does not employ voice recognition capabilities and the authors do not justify the scalability of the system.

III. Use Case Scenario

We developed a use case scenario to demonstrate the applicability and usability of PoT in home automation applications, as depicted in Fig.1. The prototype consists of (1) ***IoT Gateway***: which is an embedded Linux platform, namely Raspberry Pi 3 Model B+, running Asterisk, Open-source IP PBX engine. The IoT gateway encompasses Google Assistant using a low-level API offered by Google. The integrated Google Assistant in the IoT gateway is interfaced to Asterisk, as illustrated in Fig.2. It is responsible for handling user utterance and system responses and adds voice control and natural language understanding (NLU) capability layer to the IoT gateway. The IoT gateway maintains and updates a freely-available, real-time, and cloud-hosted database, namely Firebase Realtime Database from GCP (Google Cloud Platform), that contains information about all of the IoT devices connected to the IoT gateway. The key strength feature of employing this database is that it provides for information synchronization among all connected parties to the database on a real-time basis which supports potential integration with other applications and services; (2) ***IoT Devices***: which include all connected objects to the IoT gateway. IoT devices do not necessarily implement the TCP/IP stack to get connected to the IoT gateway, since the IoT gateway provides different less processing-intensive communication protocol options for simple devices with constraints regarding the processing and/or power consumption. The employed IoT devices in the proposed system include a SimpleLink Multi-Standard CC1350 SensorTag from Texas Instruments (TI) which is connected to the IoT gateway through Bluetooth Low Energy (BLE). The SensorTag encom-

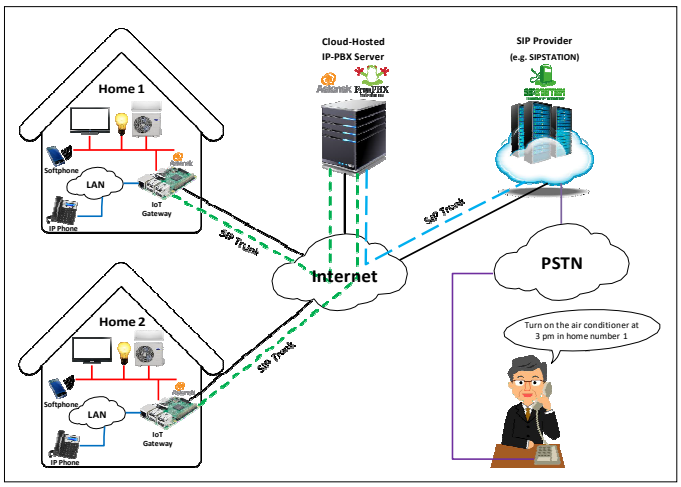


Fig. 3: SIP trunk implementation by the proposed system.

passes low-power MEMS (micro-electromechanical system) sensors that measure the environmental conditions, namely ambient temperature, relative humidity, barometric pressure, and light intensity. Besides, IoT devices in the proposed system also incorporate a relay board that consists of four relays. These relays can be individually triggered by the IoT gateway according to specific commands or events.

The IoT devices connected to the IoT gateway can be individually monitored and commanded from outside the home using the PSTN. The user dials the landline phone number connected to the system, invokes the associated chatbot, and performs a command or sends a query. The chatbot recognizes the user intent, identifies entities in the user speech and then executes the command or responds to the query from the appropriate device accordingly. Harnessing the power of Dialogflow, complex conditional voice commands can be implemented to take actions on some devices based on the information acquired from other devices.

IV. Potential Applications

A. Scalable Home Automation System

To allow for system scalability and leverage the use of the embedded Asterisk servers in the IoT gateways to its maximum, a cloud-hosted IP-PBX can be employed. According to RasPBX FAQ [35], Raspberry Pi 1 can typically handle 10 simultaneous passthrough VoIP calls, after which voice quality degrades considerably. It's worth noting that some of the processing power is already consumed on other system functionalities. The cloud-hosted PBX server aims at relieving the burden of VoIP processing from the IoT gateways, allowing for better hardware safety and operating system stability as the system scales. The cloud-hosted IP-PBX is mainly meant to handle VoIP calls from outside the local LAN of the IoT gateway and to provide a unified interface to monitor and control multiple IoT gateways. The cloud-hosted PBX server is connected to the IoT gateway through the use of SIP trunking [36]. SIP trunking is a virtual connection that leverages the use of the Internet to provide for voice and video communications in UC solutions. It eliminates the use of a physical connection to a telecommunication company and hence it reduces communication costs and eradicates wasted resources. Moreover, since SIP trunking is a virtual connection, adding lines and modifying services are easy and dynamic which provides flexibility and enhances potential system scalability. SIP trunking implementation in the proposed system is illustrated in Fig.3.

B. Intelligent and dynamic IVR system for enterprises

The integration between Asterisk and Google Assistant, illustrated in Fig.2, can be furtherly used to build an intelligent and dynamic IVR system for enterprises. At this point, instead of building the conventional static IVR menus that could not adapt to changes in the enterprise, we can exploit the NLU capability to define entities in Dialogflow that are then used to extract useful facts from what the caller says and forward the call accordingly to the suitable destination. This is believed to reduce the response time for customers and improve their satisfaction. The same concept can also be used to query information from the suitable IoT device connected to the IoT gateway to answer users questions which will be beneficial in public sensing applications.

C. Intelligent phone dialing system (location transparency call)

Another incentive application that can leverage the integration between Asterisk, Google Assistant, and real-time databases, is the tracking of employees within the premises to allow for intelligent phone forwarding/dialing systems. In this scenario, an RFID reader is attached to each door entry in the premise and is connected to the IoT gateway. When an employee, carrying an RFID tag, passes by a door entry, the IoT gateway keeps track of his/her location and updates the real-time database accordingly. Available phone extensions in each room are also maintained by the database. A caller just needs to invoke the attached chatbot and asks about the name of the user to be called. The system then recognizes the called name, queries the database for his/her current location, and passes the attached extension number of his/her current location to the embedded Asterisk server which will initiate a phone call to that number. Leveraging the interconnectivity of the IoT gateways, as explained in section IV-A, this application can be widened to a larger scale to serve multi-site enterprises, for example, as depicted in Fig.4.

Location transparency calls can also be exploited to another higher extent. For instance, even if the called person does not exist within the premise, the embedded Asterisk server can automatically seize the SIP trunk from the ITSP to make an outbound call to the requested person's mobile phone. Furthermore, artificial intelligence can enhance the application of location transparency by choosing the optimum way to reach the called person based on some criteria. The system might also prefer to call the person using the internal extension or the PSTN line in his/her current location rather than his/her

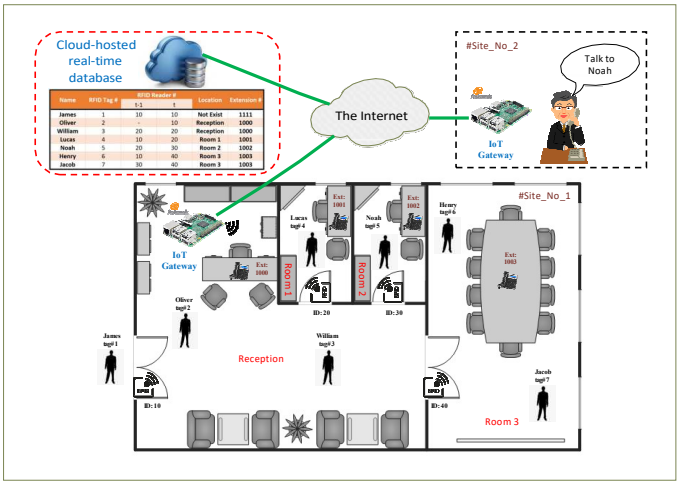


Fig. 4: Location Transparency Call overview.

mobile phone in case the mobile signal strength is weak and/or to reduce the mobile radiation exposure to the called person by prioritizing internal extensions and landline phones to call the person whenever available at his/her current location. This application is expected to allow fast reachability to persons with high mobility within the premises, like physicians in hospitals.

D. Asset tracking

Using a similar concept to what is used in section IV-C while discussing the location transparency call application, the new paradigm presented in this paper is a perfect fit to be applied in asset tracking. Using the variety of available communication protocols to the IoT gateway which can encompass a lot of IoT devices, the system can be used to track assets within the premise using a simple voice call to the system. Combined with the newly emerged TinyML technology, which enables machine learning algorithms on embedded platforms, the IoT devices can autonomously predict problems based on some criteria and auto notify administrators and vendors about the need of regular and/or preventive maintenance via phone calls, before the problem actually affects the organization's workflow and costs it a lot of money.

V. Conclusion

This paper introduces "*Phone of Things (PoT)*", a new computing paradigm that extends the connectivity options of IoT systems by allowing them to be managed and controlled through the ubiquitous telephone network infrastructure. Individuals and enterprises leverage their rarely used landline telephone as a medium to remotely access and control their resources/devices using a simple phone call to their landline telephone number and intuitive spoken commands. PoT leverages the utilization of the existing UC solutions within the premises of enterprises beyond just making and receiving calls. PoT can also enable the on-desk phone set to monitor and control all appliances within the premises. PoT is expected to enable incentive IoT applications that could benefit from the integration among the enabling technologies behind PoT. The potential domains applications are countless and could be game-changing in the IoT domain.

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