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Performance Analysis of End-to-End Sensor-to-Cloud Personal Living Platform

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Abstract

This paper presents a performance analysis of the end-to-end sensor-to-cloud personal living platform. The analysis is based on a typical architecture starting from a single sensor and actuator and continuing to the virtualized services at smart dust, dew, fog and cloud level. The system is diverse and allows interconnection of different sensors/ actuators technologies directly or throughout gateways. The experiments in a living lab presented use energy harvesters and ZigBee PRO sensors. The results from sensor network are applicable for non-real-time and non-critical data connection. As a final conclusion, we claim that for critical and non-critical measurements that need to be supported in a typical living environment there is a necessity to use different priorities of the services and different sensors as well.

Peer-review under responsibility of the Conference Program Chairs.

Keywords: sensor technology, cloud, performance analysis, living lab, non-real-time communication, critical and non-critical data

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1. Introduction

Nowadays, there are too many different devices and software interconnected in the network. The interworking capability of such a heterogeneous network and interoperability between network elements is a serious problem. Every new medical, fitness, wellness, active-aging, health-related device and software is usually supported by cloud based service. Due to the business solutions cloud services are not interconnected and do not share data. Possibility of data migration between different generations of the devices and nodes coming from different producers is still not well supported. The possibility to integrate multiple different devices into a personal living environment (PLE) that is context-aware is still a wish. When the PLE belongs to the person that is temporarily or permanently in care need it is not straight forward how the data could be shared and managed from different places and by different persons. In this paper, we try to define PLE that is end-to-end sensor-to-cloud solution and will allow easy integration of the devices, algorithms, software at smart dust, dew, fog or cloud virtual level. Platform virtualization allows easy application of the algorithms for big data analysis, data acquisition, data migration, context analysis, etc. regardless of the access part with specific traffic sources. The opposite is also true, i.e. being virtualized, the platform will allow adding/ removing/ reconfiguration, evolution, changing of the access network and traffic sources regardless of the cloud part of the network.

This work is organized as follows. We start with brief review on the state of the art in PLE. Then we present the architecture of the personal living environment mentioning the sensor part, gateways, smart dust, dew, fog and cloud computing parts keeping in mind that part of the nodes could be mobile and portable. The experiments done in the living lab are explained next as well as some results derived. We conclude with comments on applicability of the work and future research directions.

2. State of the Art

Internet of Things (IoT) and 5G are hot topics and there are many analysis and published research in this area. They concern different aspects like security, protocols, technologies, and advertise new platforms or frameworks. These activities are surrounded by a complex market of software and device vendors, telecoms and IT service providers. Under these circumstances, it is easy to be carried away from the main motivation for these technologies to come into existence – namely to provide good performance for the business and end-users and assist in their living[1,2]. As of some recent estimates (Forbes), it is expected that IoT market will double within the next 3 years, reaching 31 billion devices by 2020 and even quintuple by 2025 to more than 75 billion devices[3]. With the number of devices growing exponentially, we have hyper exponential expectations for the amount of data generated. All these data need to be turned into actionable and contextualized information and IoT realization success is highly correlated to our ability to gain insights hidden in seas of data[4]. There is still a gap between making IoT in general and making IoT workable. This is not possible without interoperability, big data analysis and sharing, data visualization, mapping, filtering, dependence analysis, accuracy of the presentation, machine learning and computer intelligence[5]. This could be done throughout open design and use of standard interfaces, protocols, data interchange formats, open APIs. Where necessary gateways could be applied for better connectivity and interoperability[6]. Conformance to the existing standard solutions like medical services standards, home appliances standards, home and business automation standards is considered at different levels of scale and design[7]. There is a good analysis of the ambient assisted living solutions used for further standardization in European Commission and ETSI[8,9]. The basic technical solution is having minimal requirements towards the infrastructure due to the price. Personal and smart weather stations are in high demand in US and in developed economies of European Union[10]. Medical applications and devices are very expensive due to the high accuracy requirements and specific features[11]. Part of the integrated solutions look like hobby-based and toys[12]. With the increased demand for compatibility, wireless communication and the utilization of open standards, these sensors and their controllers are becoming much easier to integrate.

Interconnection and reliability is another important issue in the PLE[13]. We already investigated peer-to-peer and client/server connections, backup and duplicated connections. Most of the solutions are mobile, i.e. connections are heterogeneous and comprise of 3G/4G/5G, Wi-Fi to communicate with the smart dust, dew, fog, cloud infrastructure. Gateways might be based on the Microsoft Azure IoT Gateway SDK with plugin architecture and will support a number of standard protocols for data interchange like Message Queue Telemetry Transport (MQTT), Modbus and Profinet to connect to sensors and stations and bridge them to the cloud. For devices with built-in network connectivity, the cloud platform supports also present standard interfaces over the most common protocols like HTTP, MQTT and Advanced Message Queuing Protocol (AMQP). Traffic and performance analysis is another important issue in PLE design. The traffic from sensors, data centers, local servers is no longer exponential and this requires special attention during service creation. Preliminary analyses of the traffic from sensors could be seen in our previous work[2]. Design analyses based on services and traffic sources we presented without details in a book chapter[14]. Services and possible application scenarios are analyzed in another book chapter[15]. Psychological aspects and perception of the services are shown in the edited book[16]. Traffic priorities are analyzed in a conference paper[17].

3. Personal Living Environments Architecture

The architecture of the PLE presented here is generic. It starts with sensor network, follows the data way through gateways and Open APIs to the smart dust, dew, fog, cloud level. The sensor technologies could be of different type, support or not forwarding, proxies, unidirectional and bidirectional communication, data, image, video streaming, etc. In Fig. 1 we presented a topology made in the living lab using ZigBee PRO sensors. The left sensors/ actuators are pure traffic sources, the ones in the middle are proxies that forward the messages from the sources. The right sensors/ actuators are sinks, coordinators of the sensor network and gateways to other parts of the platform.

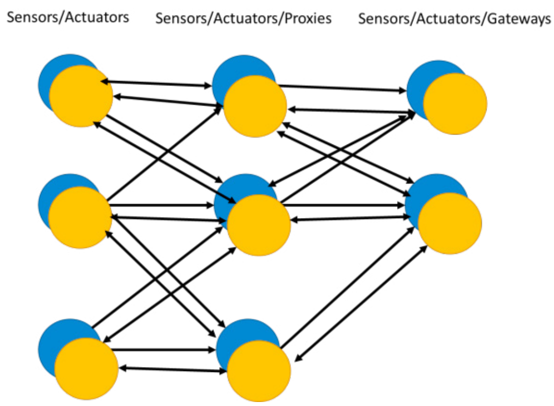

Fig. 1. Ad hoc experimental sensor network topology.

As a matter of fact, the sensors in the entire network are the same. They are configured differently. Pure traffic sources could sleep. Proxies, coordinators, sinks, gateways could not sleep and could forward messages. The network is ad hoc, i.e. while changing the sensitivity, transmission power of the sensors, or distance between them the topology is changing. The number of connections between sensors also depends on their operational range. Our experiments in the lab with multiple forwards demonstrated that the reasonable numbers of hops in sensor network is up to 5-6. The data transmission could not be done in real-time, i.e. in less than 150 ms end-to-end. Generally speaking sensor networks are appropriate for the PLE without typical general types of services like Voice over IP or Video over IP. The support of the real-time services should be done by other technologies. There are authors that consider smartphones as sensors/actuators for this purpose. In this case real-time services are naturally embedded into the platform.

In Fig. 2 we presented a general view of the platform consisting of sensor networks, mobile and fixed gateways or Open APIs and the cloud. Aiming almost end-to-end platform virtualization we place the network and platform management, configuration, monitoring, data processing, data mining etc. at cloud level. The only processing left for the sensor network coordinators and gateways is possibility to perform data acquisition, time stamping and other possible data conversion that will allow better storage and processing in the cloud. There might be different topology solutions for the platform also at cloud level. For example, part of the sensor networks could be connected to local controllers and OLE for Process Control (OPC) servers that are enough intelligent and powerful to store and process data locally while identifying alarms. They constitute so called smart dust or dew levels of the cloud (Fig. 3) depending on the capability of the servers and storages. For example, dew level could be software defined network of a family at service provider premises, could be powerful home server or both depending on the business case and configuration.

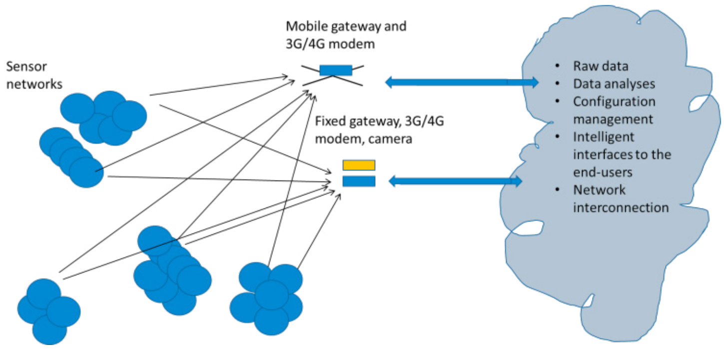

Fig. 2. From sensors to the cloud through heterogeneous technologies.

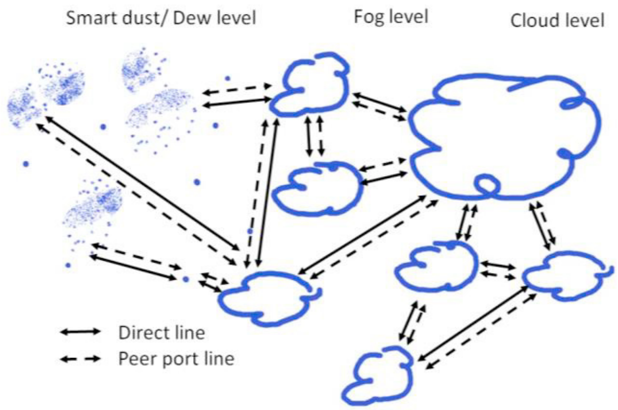

Fig. 3. Smart dust, dew, fog, cloud level of personal living environment.

Fog level presents the service provider, regional service, national caring system, district service. There are high capacity server farms and data centers that support more specific and capable information and communication services like raw data storing, data mining, configuration management, network interconnection, data sharing, definition of main services for primary, secondary and tertiary end-users. Primary end-users are subjects for whom the service is created. These are patients, children, people with temporary disabilities, family members, home and environment appliances in machine-to-machine communications. The secondary end-users are caregivers who use the service to support primary end-users and devices. These are family members, caregivers, doctors, teachers, robots, etc. The tertiary end-users are all other possible end-users like insurance companies, national health insurance authorities, health agencies, municipalities supporting smart services, e-governments, etc.

Cloud level could be national or international or global and could support the services regardless of the local legislation policies and boundaries. The virtualization process allows development of the services at smart dust, dew, fog, cloud level regardless of the deployment processes in the access network. It presents possibilities for platform interconnection and data mobility at any stage of the platform development. The use of smart gateways and Open APIs will allow easy technological support for different producers, interoperability supported by standards, existing and in the process of creation. Therefore, the platform will be highly adaptable to the market needs and will allow sustainable development along the service commissioning.

4. Experiments and Results

The experimental results presented here use the topology in Fig. 1. There are four end-sensors, four proxies and four sinks that see each other in the radio channel or not depending on the configuration and distance. The sensors are ZigBee Pro and they are energy harvesters. One thousand data transfers had been processed transmitting environmental data. All sensors work on the same frequency channel. The results presented in Table 1 show measured data transfer at sensor part of the network and gateway-to-cloud part of the network. Different configurations of the sensor network were tested starting from one sensor, one proxy and one sink and going to the four sensors, four proxies and four sinks. The derived experimental results demonstrate the capability of the sensors to transfer non-critical data with enough accuracy. This is because of the high delays and probability to lose packet. In fact, the traffic loss is significant when the radio channel is shared between multiple sensors. The total end-to-end delay is accumulated from the measured processing and transfer delays at sensor, gateways and the cloud. As for the critical data priorities need to be setup as shown in one of our previous papers[17]. Traffic analysis in the presence of other traffic sources as video cameras, voice over IP channels, high definition pictures (medical level, non-medical level) are a matter of further research. Data processing at the gateway depends on the load and protocol supported. The mean data transfer delay between the gateway and the cloud depends on the server load, application processing, internet connection. The last value could vary significantly up to few seconds[13] without being a subject of additional care in IP network. When the interference in the channel is high the probability of loss increases. The transfer delays depend mainly on the network configuration, traffic load and Internet connectivity. The results presented demonstrate the applicability of the technology for the non-critical data transfer end-to-end.

Table 1. Experimental results for sensor-to-cloud connection.

Experimental network	Sensor number	Mean transfer delay/ minimal/ maximal value, ms	Probability of loss	Mean transfer at gateway, ms	Mean transfer to the cloud, ms	End-to-end delay, ms
1 sensor - 1 proxy - 4 sinks	1	25/18/50	0,00	56	245	326
2 sensors - 1 proxy - 4 sinks	1	29/12/120	0,01	60	223	312
	2	7/32/119	0,09	74	243	349
3 sensors - 1 proxy - 4 sinks	1	33/13/110	0,04	55	187	275
	2	36/18/143	0,13	73	300	409
	3	37/17/133	0,25	65	271	373
4 sensors - 1 proxy - 4 sinks	1	36/13/184	0,05	54	198	288
	2	39/18/140	0,16	56	237	332
—	3	40/18/174	0,29	76	214	330
	4	43/18/180	0,47	65	381	489
4 sensors - 2 proxies - 4 sinks	1	36/17/196	0,11	45	230	311
	2	37/17/119	0,21	76	311	424
	3	33/17/146	0,05	53	265	351
	4	44/18/146	0,32	71	278	393
4 sensors - 3 proxies - 4 sinks	1	33/17/181	0,06	68	302	403
	2	39/17/153	0,31	52	185	276
	3	38/18/159	0,15	64	170	272
	4	35/17/152	0,11	54	342	431
4 sensors - 4 proxies - 4 sinks	1	37/17/194	0,15	76	196	309
	2	39/17/174	0,35	83	254	376
	3	38/17/248	0,19	49	278	365
	4	34/17/141	0,07	57	402	493

5. Conclusion

The work presented shows experimental results of the sensor-to-cloud transfer delays through gateways and proxies and delay/loss dependence on the number of sensors in the radio channel, number of forwarding proxies and number of sinks. Network configuration happened to be essential for quality of the service and quality of the experience to the end-user. The proposed sensor solutions are applicable for non-critical data transfer like environmental data in the personal living environment. Special priority schema will be necessary to be kept for the critical end-user information transferred in real-time as well as other real-time services live voice and video. Services created for the end-users could constitute different versions and prices and support different features on demand. Our future work plans are to simulate the sensor-to-cloud connectivity including smart dust, dew and fog levels as well as presenting additional services for smart dust-to-dew and dew-to-fog communication, data sharing and data mining.

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