An Economic Assessment of the Contributions of 5G into the Railways and Energy Sectors

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Abstract

This paper presents an economical assessment of the benefits of introducing 5G technologies into pilot use cases pertaining to the railroad transportation and energy sectors. For each of the pilots, undergone by EFACEC Engenharia e Sistemas and EFACEC Energia, respectively, under the scope of the H2020 5Growth project, evaluates the expenditure and benefits expected from introducing 5G capabilities over their on-going operations. This evaluation is expressed regarding the Portugal case, and are also scaled to assess the European-wide case. The main objective of the study summarized in this paper is to understand if solutions proposed by the H2020 5Growth project, and 5G as a whole, are also advantageous from an economic point of view. The results of the techno-economic analysis reported in this paper show, on a European scale, millions of euros saved by the different stakeholders involved in the deployment of 5G solutions.

Introduction

The 5th generation of mobile networks, or 5G, distinguishes itself from previous generations by going beyond radio and core network evolutions targeting performance and capacity, and actually tapping into the cloudification of its operations and service provisioning [16] . By relying on the dynamics and flexibility provided by cloud-based mechanisms, telco providers can not only reduce operational costs, but can instantiate, adapt and remove service provisioning at much larger scales and speeds. As such, the integration of Network Function Virtualization, Software Defined Networking and Network Slicing have become powerful tools in enabling providers to tackle the challenges of serving verticals via cloud-enabled public and private mobile networks, who until now had to resort to specific vertical-targeted infrastructures with increased cost. As a result, 5G not only allows for better performance, but actually allows for new scenarios to be available, and is able to be extended to new consumers [17] .

However, reaping the benefits of these capabilities by the end users is not just a matter of replacing their end-user equipment [15] . This is particularly troublesome when it comes to the introduction of new types of users (such as the ones which, until now, have resorted to dedicated certified private networks). The claims for added benefits and performance can be clear in the language of a telco-world engineer. However, to the other side (namely, the verticals) there is an enormous amount of concepts and possibilities which can feel alien, even with the supportive aid of network service providers and vendors.

Therefore, parallel to the technical efforts in solving the issues associated to shortening the gap between these players, lies the need to evaluate the actual economical benefits of introducing 5G technologies into the industrial activities of vertical players.

This is where this paper contributes. It analyses two pilots belonging to the H2020 5Growth[1] project (focusing on the railroad transportation and energy sectors, respectively) and provides an economical evaluation based on the benefits introduced by 5G, showing the economical feasibility of embracing the next generation of telecommunications. Expenditure and savings items are presented, based on assessments done by the verticals, based on data for Portugal, and scaled for an all-out European level. As a result, the paper presents preliminary numerical evaluation about the possible new revenues obtained by the 5G's envisaged innovations and solutions.

The remainder of the document is structured as follows. Section 2 presents the H2020 5Growth project, along with the selected vertical pilots, showcasing their requirements. This is followed by section 3 which presents the general considerations for the economical evaluation, followed by the assessment done for each pilot, emphasizing the different benefits and their contributions. Finally, the paper concludes in section 4.

[1] H2020 5Growth - 5G-enabled Growth in Vertical Industries - https://5growth.eu/

Vertical Pilots' Overview And Requirements

The pilots showcased in this section are being built and deployed under the scope of the H2020 5Growth project. This Phase 3 5G-PPP H2020 project is running in the framework of the 5G Public Private Partnership (5G-PPP) Phase-3, Part 3 "Advanced 5G validation trials across multiple vertical industries". It pursues the technical and business validation of 5G technologies from a vertical's point of view, following a field-trial-based approach on vertical sites. The project empowers vertical industries, such as Industry 4.0, Transportation, and Energy with an AI-driven Automated and Shareable 5G End-to-End solution that will allow these industries to simultaneously achieve their respective key performance targets [12] . The project leverages enhancements done over the base 5G design by the H2020 5G-Transformer project **[1]** [14] , and further increments them by providing a whole new set of innovations. These innovations allow verticals to interface with the 5G End-to-End platforms, receiving their service requests and building the necessary network slices on top, providing as well closed-loop automation and SLA control for vertical services lifecycle management, and AI-driven end-to-end network solutions to jointly optimize Access, Transport, Core and Cloud, Edge and Fog resources, across multiple technologies and domains [13] .

In addition, H2020 5Growth bridges the gaps between projects resulting from 5G-PPP Phase-1 and Phase-3 projects by leveraging the potentials of ICT-17 platforms (e.g., 5G-EVE**[2]** and 5G-VINNI**[3]**), using them to support the deployment of test site trials. H2020 5Growth's consortium is composed by 19 partners from Europe, and features pilots in Spain, Italy and Portugal.

The city of Aveiro in Portugal, is the home for two of the project's pilots, pertaining to the railway transportation and energy vertical sectors, respectively. These pilots have as key participants the Instituto de Telecomunicações, EFACEC Engenharia e Sistemas (EFACEC_S), EFACEC Energia (EFACEC_E) and Altice Labs. The pilots are deployed over infrastructure that resides in the Aveiro University Campus (where Instituto de Telecomunicações is located, and where a H2020 5G-VINNI test site is located). These are the two pilots of the project over which this project focuses on, and are detailed next, along with their requirements for the economical assessment.

2.1 Transportation Pilot

The transportation vertical pilot, led by EFACEC Engenharia e Sistemas (EFACEC_S), proposes to use the 5G slice capabilities in order to replace the wired communication used nowadays on railway level crossing environments and reinforce the safety conditions by transmitting video images to train drives and maintenance agents, supported by 5G communications. This is the basis to deploy two use cases: Safety Critical Communications (figure *1*) which are focused on railways signaling operations and Non-Safety Critical Communications (figure *2*), which provide additional information (video images), to reinforce the safety conditions avoiding accidents at Level Crossing area.

2.1.1 Trial Use Cases

Figure *1* illustrates a traditional railway level crossing and the main devices involved in the signalling operation (axle counter/train detector system, road signals, level crossing signal protection, half-barriers and the Controller's cabinet). In the presence of an approaching train, the train detector system sends data messages to the level crossing (LX) controller, to inform that a train is approaching the level crossing and to transmit the status of the equipment on the track. The LX controller then must start the set of actions to assure safe conditions to the train, cars and people. After detecting that the train has left the LX, the peripheral devices must return to normal state. Therefore, the LX controller retrieves the sensors information to automatically define the position of the half-barriers, the traffic lights and the protection signal. In a level crossing signalling system, the communication between the controller system and the peripheral devices (train detectors, signals and barriers) is typically assured by means of copper cable wires, involving considerable costs regarding the communications infrastructure.

In the pilot, it is desirable to replace cabled based networks by 5G technologies, assuring two types of critical communications: safety critical and non-safety critical.

In the field trial, 5G communications is used to support railway signaling operations, in particular to meet railway level crossing communication requirements (M2M), namely:

- Use-case 1: for safety critical communications from approaching train detectors (Strike In detectors) to the level crossing controllers;
- Use-case 2: for transmission of level crossing real-time video images to mobile devices on approaching trains and to maintenance agent's tablet devices.

Regarding Use-case 1, as shown in figure *1*, 5G technologies are used to send the railroad sensor information detecting a train approaching (and leaving) the vicinity of a LX, into the controller in charge of raising or lowering the half-barrier. This allows the railroad operator to replace the usage of cable with wireless communications, providing savings in terms of deployment associated with the construction work involved in cable deployment.

Regarding Use-case 2, as shown in figure *2*, the performance capabilities of 5G technologies are also explored in order to sending high-resolution video surveillance footage of the LX to the on-coming train, as well as to mobile maintenance teams in the vicinity. It is important to highlight that both use-cases rely on the usage of independent network slices, allowing for the establishment of isolated, reliable and high-performing connections, at a public network deployment.

2.1.2 Target Business KPIs

Here we will summarize the target business KPIs for the transportation pilot, considering the required 5G service, the aimed output and the intended benefit.

2.1.2.1 5G Service required

This pilot requires URLLC in order to transmit the safety critical communications between the Level Crossing (LX) controller and the level crossing train detector. And eMBB to transmit high definition video to the train controllers and also URLLC to transmit alarms and controller status to the maintenance agents.

2.1.2.2 Output

In this pilot a complete half barrier level crossing control system in a railroad crossing in the Aveiro harbor premises will be installed. The system will include a LX controller cabinet equipped with SIL48 safety PLC, an axle counter train detection system, EMC protections devices, an uninterruptible power supply and a 5G CPE. Each approaching train detectors will use a 5G CPE to communicate with the level crossing controller. Two half barrier drives, controlled by the LX controller, will protect the entry of cars in the rail crossing during the train approaching and passing. All the communications will be supported by safetycritical protocols (Safe Ethernet and RASTA), developed and certified under the scope of the project. Besides, a train engine will be equipped with an onboard 5G tablet, a level crossing with an HD video camera and a server that will connect the LX controller and the camera to the cloud using 5G communications. A mobile tablet will allow the monitoring and control of the level crossing systems. An app running in the maintenance agent tablet will allow the remote control of all LX system.

2.1.2.3 Benefit

The solution should reduce the level crossing capex by 20%, the XSafe (EFACEC_S Level Crossing solution) level crossing system product will become more competitive with respect to the traditional wired level crossing signaling solutions. The level crossing time installation will be reduced by 50%. Also, the development of a new market for the mobile video level crossings safety reinforcement with public standard communications. The remote asset monitoring using 5G will allow much more competitive, flexible and agile solutions compared to the actual wired solutions, allowing the reduction of costs and service response time, and creating new market.

2.1.2.4 KPIs

From the previous considerations, the following list of target business KPIs can be extracted:

- Reduce system CAPEX by 20%;
- Reduce system installation cost by 50%;
- Reduce installation time by 50%;
- Reduce cable cost by 80%;
- Reduce maintenance visits by 20%;
- Reduce service response time by 20%.

2.2 Energy Pilot

EFACEC Energia's (EFACEC_E) energy vertical pilot will involve the deployment of two more use cases:

- Use-case 1: Advanced Monitoring and Maintenance Support for Secondary Substations MV/LV Distribution Substation (figure *3*), consists of a system to assist the maintenance team when repairing the substation by providing information with augmented reality;
- Use-case 2: The Advanced Critical Signal and Data Exchange Across Wide Smart Metering and Measurement Infrastructures (figure *4*) use case will deploy a system to use the last gasp of energy before an outage to save and transmit important information to identify and prevent greater problems.

2.2.1 Trial Use Cases

The pilot will address the advanced monitoring and maintenance support of Low Voltage (LV) smart grid infrastructures within the secondary substations, including surveillance HD video streaming from local and mobile cameras. It will also address the experience of on-demand local augmented reality, accessible from the control centre and on maintenance crew mobile devices, together with the empowering of the infrastructure automation.

Without 5G, the communication between intelligent electronic devices similar to the ones that are present in the pilot is made mainly through radio frequency technologies (LoRa and 4G) and Power Line Carrier (PLC). LoRa technology enables wireless communications over long distances with minimal energy consumption. The communication through PLC supports a wired communication channel with low operation costs and low bandwidth. 4G mobile communication technology enables mobile web access, IP telephony, high definition mobile TV and video conferencing. However, all these technologies are not effective for priority services, such as the energy services.

The main purpose is to validate advanced smart grid control solutions through use cases promoting the concurrent usage of network resources, which must be shared among multiple applications demanding different service requirements within an LV-Smart Grid area, framed in a wider smart city/campus. Considering a LV smart grid infrastructure, equipped with advanced monitoring and control solutions for the secondary substation(s) and distribution cabinet(s) automation, i.e. Distribution Transformer Controllers (DTC), sensors and meters, and empowered by 5G technologies, different use cases will be further explored across field trials.

Regarding Use-Case 1, shown in figure *3*, 5G will be key in assisting the remote operator and then the crews dispatched to the field to better assess the severity and the impact of the outage they are facing. From the local surveillance systems available in the secondary substation, an HD video signal must be streamed in nearly real-time to the control centre and to the mobile devices of the maintenance crew. Aware of the infrastructure state, the crew and the operator managing the intervention, can be more efficient when implementing contingency and service restorations measures. Locally, the crews should also be capable of assessing and broadcasting an augmented reality experience on the affected critical assets. The crews will thus gain an insight over the damage magnitude and the immediate consequences of the outage they are dealing with, leading to shorter response times.

Regarding Use-Case 2, shown in figure *4*, As critical data from remote real-time monitoring and control must be exchanged between several smart devices deployed across an entire infrastructure, the synchronisation is particularly relevant, ideally with delays of a few milliseconds. Here, the use case concerns itself with last-gasp features of smart devices, once fed from the bus they are monitoring, and they can process the value of the data exchanged during that critical last-gasp process. In other words, the control and management systems can extract relevant information from the last-gasp data received in order to perform faster and more precise fault detection and location. Low latency communications are therefore required immediately after the power outage is detected by the device, to minimise the demand on the device power supply, enabling the device to perform the required housekeeping and to hold the communication channel active to send the last-gasp message before the device power supply storage capability is totally exhausted. An even lower latency and higher connection density are required when trying to synchronise the referred smart devices – meters and sensors –, for data exchange, which will improve the general quality of the gathered data, benefiting advanced control applications dependent on correlation analysis and big data processing.

5G will have a key economic role in both scenarios. An enhanced performance from the critical signals' communication, across wide smart sensors infrastructures, is crucial for the deployment of advanced control applications. Also, the advanced monitoring and maintenance support of secondary substation is crucial to improve the outage management and match the high reliability indexes required within a smart grid environment. Supported by smart devices, e.g., sensors, distributed controllers and concentrators, cloud based edge, electric data meters and more centralized advanced management systems with very low latency communication, the pilot permits targeting an agile signal exchange, between the devices deployed across the network, placed within an area up to 10 , and both the distributed intelligence and the centralized controllers. This will enrich the information and the current status of low-voltage distribution networks. From the standpoint of maintenance and operation, it will take advantage of 5G's communication capabilities to streamline the process, delivering robust results. Edge computing will add enhanced distributed control and the capacity to run critical applications for the supervision and control of multiple LV-Smart Grids, and the advanced management of LV Micro Grids.

2.2.2 Target Business KPIs

Here we will summarize the target business KPIs for the energy pilot, considering the required 5G service, the aimed output and the intended benefit.

2.2.2.1 5G Service required

This pilot requires eMBB to support the video camera and augmented reality streaming, complemented with additional URLLC services for the time sensitive augmented reality application. It also requires mMTC to connect a high number of smart meters and URLLC for the transmission of critical signals.

2.2.2.2 Output

An advanced monitoring and maintenance support should be available to assist the remote operator and then the crews dispatched to the field to better assess the severity and the impact of the outage they are facing. From the local surveillance systems available in the secondary substation, an HD video signal must be streamed in nearly real-time to the control center and to the mobile devices of the maintenance crew moving to the site. Aware of the infrastructure state, the crew and the operator managing the intervention, can be more efficient when implementing contingency and service restorations measures. Locally, the crews should also be capable of assessing and broadcasting an augmented reality experience on the affected critical assets. The crews will thus gain an insight over the damage magnitude and the immediate consequences of the outage they are dealing with, leading to shorter response times.

2.2.2.3 Benefit

Enhanced performance from the advanced monitoring and maintenance support of secondary substation is crucial to improve the outage management and match the high reliability indexes required within a smart grid environment. Additionally, the improvement of the advanced critical signal and data exchange across wide smart metering and measurement infrastructures is crucial for the deployment of advanced control applications.

2.2.2.4 KPIs

From the previous considerations, the following list of target business KPIs can be extracted:

- Reduce SAIDI for LV (Low Voltage) in 15% (System Average Input Duration Index (SAIDI) measures the average of the total long duration of interruptions affecting the average delivery point for a given year);
- Reduce ENS (Energy Not Supplied) in 5%.

[1] H2020 5G-Transformer - 5G Mobile Transport Platform for Verticals - http://5g-transformer.eu/

[2] H2020 5G-EVE - 5G European Validation platform for Extensive trials - http://5g-eve.ey/

[3] H2020 5G-VINNI - 5G Verticals Innovation Infrastructure - http://5g-vinni.eu/

Economical Evaluation

5Growth aims at developing and validating a business model for the use cases in a coordinated way, directly engaging all the stakeholders involved, especially vertical actors and their customers, whilst protecting strategic EU IP and ensuring long-term social acceptance and economic sustainability, extending beyond the lifespan of the project through a joint commercialization plan. This business model enables involved stakeholders and external international actors to understand and exploit the project results. For this reason, a methodology devoted to understanding the economic advantages of the adoption of the 5G in general and the solutions envisaged in 5Growth has been considered and adopted to the project's use cases.

Traditional business analysis (e.g., the one performed by the 5G-Crosshaul project described in [1]) focuses on the difference in expenditures between a given situation with and without the innovative solution. Since 5G and its application (i.e. 5Growth Innovations) represent a real revolution and not only provides the same results with lower costs, but opens a door to new services and products, this classic approach is not enough. Therefore, a new methodology will take into account not only the traditional cost-reduction approach, but it will also consider the new product/services developed and the new revenue streams associated.

Having as our main goal to show the benefits introduced by 5G and 5Growth and to demonstrate that the project use cases are economically viable, the study includes the benefits for all the stakeholders involved, including EU citizens. Towards that end, we performed a detailed analysis, identifying for each pilot a set of items where the introduction of new technologies (i.e. 5G and all the solutions envisaged by 5Growth) can bring benefits from an economical point of view. Some benefits refer to investment (i.e. Capital Expenditures - CapEx), other to operation (i.e. Operational Expenditures – OpEx) and finally new revenues (RE).

Some of these savings, specially CapEx savings, are often long-term savings that should be annualized to be able to be compared. By adding all the values, annualized when required, we obtain the Yearly Total Value (YTV), which is the parameter that will allow us to compare between legacy and new solution networks:

$$YTV = \sum_{i=1}^{N} \frac{CAPEX_i}{AP_i} + \sum_{j=1}^{N} OPEX_j + \sum_{k=1}^{R} RE_k$$

In this equation:

- $CAPEX_i$ is the i-th component of the N identified items of Capital Expenditures, i.e. the amount of cash flow that a company uses to purchase, maintain or implement its operating assets, such as buildings, land, plants or equipment;
- $OPEX_j$ is the the j-th components of the M identified items of the Operational Expenditures, i.e. operating, maintenance and management costs;
- RE_x is the component of new revenues.

In order to harmonize the sum, each CapEx has to be annualized, splitting the investment by the appropriate Amortization Period (AP). This is the easiest way to calculate the Total Value of a system taking into account CapEx, OpEx and new revenues, neglecting inflation and cost of the money used for investment (for example interests on outstanding debts like bonds, bank loans, etc.). The analysis performed so far in 5Growth allows us to project these benefits to a European scale.

3.1 General Considerations

Despite the differences evidenced by each of the pilots, there are common items of expenditure and savings that we highlight here, based on three main pillars:

- Spectrum;
- Reduction of installation and maintenance costs;
- Better service.

Spectrum can actually represent a cost, instead of a savings item. Concretely, operators have access to 5G frequencies by paying nation states for spectrum portions. However, in the end, this cost is actually passed down to end users, representing an expense that was not present in solutions that did not include wireless communications. However, this expenditure can be regarded as an investment, as it enables 5G capability and, therefore, the technologies that open the door for other savings related with the two following pillars. Additionally, it also enables savings or increase in revenues associated to the individual use cases, which will be analyzed in detail in the following sections.

Regarding **reduction of installation and maintenance costs**, personnel costs pose one of the largest cost factors in a company's budget. New technologies relying on 5G connectivity allow greater flexibility for the installation, upgrade, and maintenance of production and control elements. Commonly, such operations no longer require the presence of an operator in the premises (which impose long and expensive transfers), and can instead be managed remotely. Consequently, it will reduce operating costs and, when more important upgrades are at stake, will also reduce investments.

For the **better service** pillar, 5G connectivity, along with with advanced visualization and sensor systems, allows to obtain unprecedented new levels of control on safety and quality. As a result, better work quality can be achieved and better products and services can be offered to customers. In the manufacturing sector, a more streamlined and efficient quality control allows to reduce the amount of semi-finished products that are discarded due to low quality and to speed up the production chain. This translates into an increase in the number of finished products per unit of time and, therefore, an increase in revenue.

We provide next a detailed analysis of the two vertical Pilots, reporting numerical preliminary evaluations about savings and new revenues obtained by the adoption of the 5G (not only 5G as a general technology, but also from the 5Growth-specific) envisaged innovations and solutions.

3.2 Transportation Pilot

3.2.1 Train Accidents

The use of 5G in level crossing (LC) scenarios will reinforce the safety conditions and may reduce the number of train accidents. These benefits can have a significant impact in the costs associated with damages (material) and human lives (persons who can die or be injured) [2] .

According to [3] , there are currently about 120000 level crossings (LC) in the EU. Therefore, there are, on average, 50 LC per 100 line-Km. Half of these LC are active and have some level of automation and the other ones have no type of active equipment meaning that are only equipped with a St. Andrew's cross traffic sign (passive). There is a relationship between the kind of LC (active, passive/unprotected) and the number of accidents meaning that the number of train accidents is higher at unprotected LCs. The statistics show that LC accidents occur at passive LCs (39,8 %) while at active LCs this percentage ranges from 4,1% to 30,6% depending on the level of automation.

According to these considerations, we believe that the European market can accommodate 60000 new generation level crossings (automated and supporting advanced communication technologies).

Our estimations consider 5% of Safety benefits in terms of human lives, using automation and video images to reinforce the safety conditions (use case 1 and use case 2 of the Transportation Pilot). Taking in consideration total costs estimated at €1 billion per year [2] , the safety benefits represent 50000 M€ per year. EFACEC_S is considering that the average cost of transforming a passive LC in an active LC is about 150 k€. Therefore, for the estimated 60000 new LC, the total investment will be about 9000 M€, which means that only considering the economic value the benefits are considerable. This represents an average safety benefit of **683 k€** every year per Level Crossing. For the calculations we are considering that the amortization time is 20 years.

3.2.2 Installation Cost

The installation costs will be reduced once the 5G technology is adopted. The savings are related to the fact that there is no need to dig cable ditches or to install cable ducts (civil works and cable installation services).

Considering a Level crossing where a cable duct of 1200 meters (average) is needed, the installation cost is typically 30% of the total amount of the solution (an average of 140 k€ was estimated). Therefore, the CapEx savings per Level Crossing are about 40 k€.

We must consider a total cost of about 20 € per year regarding SIM cost.

3.2.3 Maintenance Cost

A traditional cable solution installation requires some maintenance services to assure the availability and communications integrity (failures, robberies) of the Level Crossing. A maintenance contract involving on average a value of 1000 € per year for each LC (2 annual site visit) is common for this kind of solution.

Since the 5G technology will overtake this type of restrictions, we estimate a reduction of maintenance cost (site visits) by 20%. **This represents a 200 € benefits per year per LC (OpEx savings).**

3.2.4 Cable Cost

In a traditional Level crossing (wired solution) the communication between the trigger point (detecting a train is approaching the level crossing) and the LX controller is assured by a data cable.

Taking a reference scenario of 1200 meters (trigger point to LX controller), a cable of 1600 meters is needed for this type of communication. This cost is eliminated by the use of 5G wireless solutions.

This represent a cable cost saving of 6400 € per Level Crossing.

3.2.5 Spectrum

The ANACOM**[1]** (Portuguese national communication regulatory entity) expects to raise a minimum of 237.96 million euros for the 5G spectrum. Penetration of mobile services reached 120.9 SIMs per 100 inhabitants in Portugal. Therefore, 12M 5G SIMs are expected, not considering the future IoT services. The spectrum cost is **19.75€ per SIM** to be amortized during the license lifetime (20 years), less than one euro per year per SIM. The pilot (which represents a LC) uses 3 SIMs: video camera and two sensors.

3.2.6 Network Operational Cost

Automated network management and configuration enabled by vertical orchestration and slicing, reduces human intervention and allows a significant decrease on Operations Expenditures/costs.

Assuming a 3 sectors macro site, the estimated OpEx is 1300€ per year [4] (a ASN - Automated Sliced Network - results in a 9% lower CapEx relative to PCN - Physical CSP network), the major contribution to TCO reductions comes from a 23% decrease in OpEx [5] . Therefore, **OpEx savings of 300€ per site** can be expected.

3.2.7 Network Resources Optimization

Automated network management and configuration enabled by vertical orchestration and slicing, optimize the usage of the infrastructure which impacts CapEx savings. Assuming a 3 sectors macro site the estimated CapEx is 20K€ per year [4] and ASN results in a 9% lower CapEx relative to PCN, the major contribution to TCO reductions comes from a 23% decrease in OpEx . Therefore, **CapEx savings of 1800€** per site can be expected.

3.2.8 Edge Computing

The edge computing is a fundamental technology to guarantee QoS with URLLC for sensors but also to offload network traffic, providing an optimized use of the network transport resources. Achieving less than 1 ms end-to-end communication latency, required for certain 5G services and use cases is an ambitious goal; towards that end the service infrastructure and User Plane Function (UPF) optimal placement at the network edge is crucial. The right placement can get over 20% cost savings for the service infrastructure deployment [6] . Considering the specifics of this pilot, CapEx savings of **4K€** can be expected.

3.2.9 Consultancy

A consultancy service is offered towards verticals and network operators with regards to architecture design, identification, selection and overall operational guidelines towards 5G/cloud deployment and usage. It also includes HW/SW trials for validation and certification of communication equipment. The cost associated mostly concerns human resources and overheads (special certification trialing may require equipment purchasing but these are discarded). For each consultancy action, it is expected that a full scientific team is able to operate within a 1-month timeframe. The first 2-weeks would be associated with the architectural training of the 5G consultancy client (either the vertical or the network operator), and the second 2-weeks would be a follow-up consultancy, in order to validate and/or certify the deployment. The main benefits that consulting brings are a potential increase in the institution funding, from added consultancy opportunities throughout Europe, due to acquired specialization on 5G+Vertical integration.

3.2.10 Summary of the Pilot Analysis

The final outcome is a preliminary evaluation on the benefits – from an economic point of view – of the solutions envisaged by the project, facilitated by the adoption of 5G. To achieve this goal, we made the effort to project the savings/increasing revenues of one level crossing to the European scale and split the contribution of 5G in general and the share specifically due to 5Growth. Table 1 reports the preliminary numerical evaluation of the economic benefits. The table addresses the previously identified economic items, and classifies them according to type, namely Growing Revenues (GR), Savings CAPEX (SC) and Savings OPEX (SO). The next column measures, for each economic item, the amount saved by deploying a wireless 5G link instead of a cable link. This is followed by the definition and indication in number of the multiplying factors associated to (in this case) the number of possible LX in EU. The following items pertain to totals, amortization time in years, and the percentage of contribution from the enhancements done in 5Growth, versus the base 5G architecture.

Table 1 - EFACEC_S PILOT, ECONOMIC BENEFITS (NUMERICAL EVALUATIONS)

Economic item	Type	Difference (cable vs 5G) [k€]	Multiply factor		Total EU [k€]	Amortization time [years]	Total EU (yearly) [k€]	% 5Growth contrib.	Total Europe (yearly) [k€] 5Growth contrib.
			What	#					
Train accidents	SO	683	# (new) 5G Level Crossing in EU	60,000	41,000,000	20	2,045,000	10	205,000
Installation Cost	SC	40	# (new) 5G Level Crossing in EU	60,000	2,400,000	20	120,000	10	12,000
Installation time	SC	10	# (new) 5G Level Crossing in EU	60,000	600,000	20	30,000	0	0
Maintenance cost	SO	0,2	# (new) 5G Level Crossing in EU	60,000	12,000	1	12,000	20	2,400
Cable cost	SC	6,4	# (new) 5G Level Crossing in EU	60,000	384,000	20	19,200	0	0
Spectrum	SC	-0.02	# (new) 5G Level Crossing in EU	60,000	-1,200	20	-60	20	-12
Network Operational cost	SO	0,3	# (new) 5G Level Crossing in EU	60,000	18,000	1	18,000	80	14,400
Network resources optimization	SC	1,8	# (new) 5G Level Crossing in EU	60,000	108,000	10	10,800	80	8,640
Edge Computing	SC	4	# (new) 5G Level Crossing in EU	60000	240,000	10	24,000	20	4,800
Consultancy	GR	6	# (new) 5G Level Crossing in EU	10	60	10	6	20	1.2
Total		**751,68**					**2,278,946**		**247,229.2**

3.3 Energy Pilot

3.3.1 QoS - System Average Interruption Duration Index

One of the main key performance indicators used to evaluate the quality of service (QoS) of a Distribution Service Operator (DSO) is the SAIDI, or System Average Interruption Duration Index. The SAIDI measures the average of the total long interruptions weighted by delivery points for a given year. SAIDI is often the indicator used by the regulators to assess the DSOs performance in terms of the Quality of Service provided to the end consumer. The legislation is rather heterogeneous across Europe and EU itself. In some countries the DSO face penalties if a given limit is surpassed, while in others there is a reward if the DSO manages to go below a given SAIDI figure. In any case, there is a financial impact in the DSO, even if the stronger impact of SAIDI is felt by the end consumer. A 20% (DSO) to 80% (End Consumer) distribution is considered.

The adoption of 5G mobile communications in the secondary substations and along the low voltage electrical grid allows the DSOs to increase the level of automation in the low voltage distribution electrical grid, and that way to react fast in the occurrence of outages keeping the service downtime at lower levels.

According to the Portuguese main DSO, comparing to the actual scenario, the adoption of 5G communications along the low voltage electrical grid supporting the described use cases can lead SAIDI LV (due to Low Voltage network interruptions) to decrease by 15%.

If we take into account that the current average value of SAIDI LV for the EU countries is according to [3] around 120 min/consumer*year, and that only a part of this value is due to incidents occurring in the low voltage network (1/3, according to the Portuguese DSO), the implementation of a large scale 5G infrastructure supporting the automation of the low voltage electric grid would allow to lower the SAIDI LV to .

This decrease will have a positive effect in the DSO costs, and also a positive effect in the end consumers electrical energy service quality.

However, due to several different approaches to the QoS from the national regulatory institutions across EU, it is not possible to monetize the SAIDI reduction effect on DSO side, on EU scale.

3.3.2 QoS - Energy Not Supplied

One of the concepts used to understand the effect of the contingencies in the electrical network operation is the ENS - Energy Not Supplied. Also referred as Power Not Supplied (PNS), it represents the amount of energy that normally would be delivered, but now is not because of an outage.

To monetize the effect of reducing lost load during contingency periods, the Value of Lost Load (VOLL) can be used. The VOLL is indeed a measure of the cost of ENS (the energy that would have been supplied if there had been no outage) to consumer.

According to the Portuguese main DSO, comparing to the actual scenario, the adoption of 5G communications supporting the automation along the low voltage electrical grid can lead ENS to decrease by 5%.

A strong constraint when extending the impact to EU scale is the fact that the VOLL can vary dramatically between European countries, and there is no overall European reference VOLL.

There are different methodologies for obtaining a credible estimate of the VOLL, the most accurate being based on surveys, and this calculation is crucial in estimating the social cost associated with energy not served.

According to [7] , the VOLL across EU countries vary between and 26€/kWh.

According to [8] , there are 260M connected customers across EU, and are delivered by EU DSOs to the connected customers.

According to [9] , the average SAIDI LV across UE member states is around .

On the other and, the European project [9] states that the electricity consumption per household is around 4000 kWh per year for the EU average, being the number of households in UE around 195M according to [10] .

Taking all these figures into account, we can estimate the ENS in EU in a 1 year period due to low voltage incidents to be: 2*4000/(24*365) = 0.91 kWh per household, reaching an EU overall of 0.91*195M = 178GWh. A reduction of 5% in this value will represent a decrease of 9GWh in ENS in EU in 1 year.

According to the VOLL range mentioned above, this will lead to savings on EU consumers side between **98M€** and **232M€** per year due to the reduction of energy not supplied to the households.

3.3.3 Control of non-authorized access

Perimeter security is an important issue in electric grid installations that stand without regular human presence like the secondary substations. Every year a significant amount is spent in maintenance and in material/equipment renewal to overcome the effects of stolen or damaged material inside the electric network installations.

The indoor camera and sensor help to prevent non-authorized access damaging and stealing or at least the identification and recovery of the stolen goods. The improvement of security in the power network installations will lower the financial impact due to willful actions perpetrated by humans, having a direct and positive impact over the DSO OPEX. This economical KPI will impact the DSO only (100%).

Unfortunately, due to the lack of available data from the EU DSOs it is not possible to monetize the impact of this economic item.

3.3.4 Local Maintenance cost

The remote monitoring of the Secondary Substations and low voltage power grid allows a more planned and timely maintenance response. With a better knowledge about the location, nature and extension of the outage event, the DSO can optimize the Work Force Management concerning maintenance teams.

According to the Portuguese main DSO, in the latest years there was an average of 7500 incidents per year in the low voltage electrical grid needing local intervention of maintenance teams.

The average duration of incident location and repair is about 100 min per incident. 50% of it is due to location time effort. It is predicted that this component could be neglected if last gasp functionality, supported by 5G communication infrastructure would be in place in the whole low voltage grid.

In the calculations below an estimated 30€ unit cost (maintenance personnel cost per hour) will be considered.

Taking the Portuguese scenario described above as reference, scoping an electrical low voltage grid size of 70000 secondary substations, and extrapolating for the EU electrical grid size considering a potential market for the automation of 3M secondary substations in Europe [8] , we can calculate the local maintenance cost savings as follows:

Therefore, the **cost savings in local maintenance to the LV grid in EU per year will be** . The DSO may have its own maintenance teams, or subcontracts maintenance services to specialized companies. Either way, the company will get a direct reduction in its OPEX. This economical KPI will impact the DSO only (100%).

3.3.5 Remote Maintenance cost

Upgrading the low voltage electrical grid communications infrastructure to 5G will heavily impact in the operations cost of EFACEC, allowing savings in highly skilled manpower concerning remote maintenance plans.

According to internal reports regarding the maintenance contract with the Portuguese DSO concerning the low voltage grid automation and considering a currently covered LV grid size of about 6500 secondary substations, it is foreseen that cost savings around 11k€ per year can be achieved with the implementation of a 5G communications infrastructure supporting the LV grid automation.

Therefore, assuming the EFACEC scenario described above as reference and extrapolating to the EU electrical grid size considering a potential market for the automation of 3M secondary substations in Europe [8] , we can calculate savings as follows:

Remote maintenance cost savings = . Remote Maintenance is a service provided by the Vertical to the DSO. The cost reduction providing that service will mainly impact the Vertical, but it shall be considered that a part of those savings may be use to get an economical advantage over the competition when offering the service to potential clients. That said, an 80% (Vertical) - 20% (DSO) distribution is considered.

3.3.6 Spectrum, Network Operational Cost, Network Resources Optimization, Edge Computing and Consultancy

The characterization of the savings aspects associated with spectrum, Network Operational Cost, Network Resources Optimization, Edge Computing and Consultancy are the same as in the Transportation pilot, pointed out in sections *3.2.5* to *3.2.9*, respectively.

3.3.7 Summary of the Pilot Analysis

The outcome is a preliminary computation on how the solutions envisaged by the project facilitated by the adoption of 5G can give their contribution from an economic point of view.

In order to estimate the impact of the economic benefits in the European Union hence demonstrating the benefits of 5Growth project, it is important to select appropriate criteria to scale the data to the EU size.

Scaling to EU size is not an easy job since the information related to electrical energy market is not available evenly across the EU countries and across EU DSOs. For instance, concerning the electrical distribution grid infrastructure, we can establish a fairly good ground for Portuguese case, but it is not possible to do the same for all the EU countries. For some cases it is possible to have an average across EU, but not for all.

Therefore, the considered needed deployment for the scale of a single pilot can be as follows:

- 1x SIM + 1x CPE per SS; 1x Secondary Substation
- 1x SIM per LV sensor in low voltage feeder; 2x LV sensors per low voltage feeder; 1x LV feeder
- 1x SIM + 1x 5G Mobile device per maintenance team; 1x maintenance team

The following table provides and insight on the comparison of the deployment at the Portuguese scale compared with an EU scale.

Table 2 - Comparison of Portuguese and EU deployment scales for the pilot

Item	Portugal	EU
Households	4,5M	195M
Secondary Substations	70000	3M
5G CPEs needed	70000	3M
LV sensors in grid	1,1M	48M
5G devices needed	1,1M	48M

In order to establish a more realistic ground to scale up for EU size, rather than consider the full size of power network and reached end consumers, the following assumptions are made:

1. Giving the current presence of EFACEC in Europeen DSOs, and the latest years growth, It is considered that EFACEC may target 10% of the EU market in the upcoming years.
2. It is not realistic to consider that all the Secondary Substations will be automated any time soon. Therefore, a 50% quota is considered here.
3. This will lead to:

    - 150k targeted Secondary Substations; 150k 5G CPEs
    - 2,4M LV targeted sensors in LV Grid; 2,4M 5G devices
    - 19,5M households reached

Table 3 reports the preliminary numerical evaluation of the economic benefits. The structure of the table is based on the one shown in table Table 1 and explained in section *3.2.10*.

Table 3 - EFACEC_E PILOT, ECONOMIC BENEFITS (NUMERICAL EVALUATIONS)

Economic item	Type	Difference (cable vs 5G) [k€]	Multiply factor		Total EU [k€]	Amortization time [years]	Total EU (yearly) [k€]	% 5Growth contrib.	Total Europe (yearly) [k€] 5Growth contrib.
			What	#					
QoS – SAIDI LV	SO	NA	Secondary Substations	3M		1			
QoS - ENS	SO	0.5 to 1.2	households	195M	98 to 232	1	98 to 232	0	0
Control of non-authorized access	SC	NA	Secondary Substations	3M					
Local Maintenance cost	SO	2.7	Secondary Substations	3M	8	1	8	0	0
Remote Maintenance cost	SO	1.7	Secondary Substations	3M	5	1	5	0	0
Spectrum	SC	- 60	Secondary Substations	3M	-180	20	-9	20	-1,8
Network Operational cost	SO	0,3	Secondary Substations	3M	0,9	1	0,9	20	0,18
Network resources optimization	SC	1,8	Secondary Substations	3M	5,4	1	5,4	80	4,32
Edge Computing	SC	4	Secondary Substations	3M	12	10	1,2	80	0,96
Consultancy	GR	6	Main European DSOs (> 100k customers)	190	1.1	10	1,1	20	0,22
TOTAL							**110,6 to 244,6**		**3,88**

[1] https://www.anacom.pt/

Conclusion

This paper has reported a techno economic analysis consisting in a preliminary numerical evaluation of the economic benefits introduced by 5G technologies into the industrial activities of two verticals belonging to the H2020 5Growth project. Four use cases, belonging to two main pilots, have been considered and analyzed, related to transportation and energy production pilots.

The main objective of the study summarized in this document is to understand if solutions proposed by the 5Growth project, and 5G as a whole, are also advantageous from an economic point of view.

The methodology adopted, and described in section 3, allows us to understand for each pilot what are the economic advantages, adding together the savings on investments, operating costs and increase on revenues. In order to consider multi-year expenses, savings and revenues the “Yearly Total Value” was introduced to obtain annualized items. Additionally, an effort has been made to understand what the benefits could be for Europe as a whole, with the objective of assessing if the economic advantages obtainable on a single pilot could be extended to similar situations throughout Europe.

From a functional point of view, the introduction of 5G in these verticals from the H2020 5Growth project allows a faster, safer wireless connectivity, with a high bit-rate and access to a large number of devices in a highly reliable way. These new or upgraded features, added to the flexibility of the wireless deployment, which reduces deployment and maintenance costs of the infrastructure, are the main pillars of the revolution that 5G will bring to the transport and energy verticals.

The results of the techno-economic analysis reported in this paper are expressive by showing, on a European scale, millions of euros saved by the different stakeholders involved in the deployment of 5G solutions. Approximately half of the achievable savings are directly attributable to the implementation of the pilots of 5Growth project.

In addition, the study is highly conservative, since it does not consider collateral social advantages, which are difficult to monetize (e.g., reducing pollution or better quality of work) and other economic advantages such as the development and marketing of products that without these new technologies could not have been produced or it would not have been commercially viable to do so.

Our results among the unanimous researches that considers 5G to be very economically advantageous, such as a study by Spoel [11] , according to which, in 2035, when 5G's full economic benefit should be realized across the globe, a broad range of industries – from retail to education, transportation to entertainment, and everything in between – could produce up to €12.3 trillion worth of goods and services enabled by 5G.

Considering future work, the study will be progressed to deal with the distribution of the benefits among the different stakeholders.

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Declarations

5 Funding

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6 Conflict of interest

Not applicable.

7 Availability of data and material

Not applicable.

8 Code availability

Not applicable.

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Figures

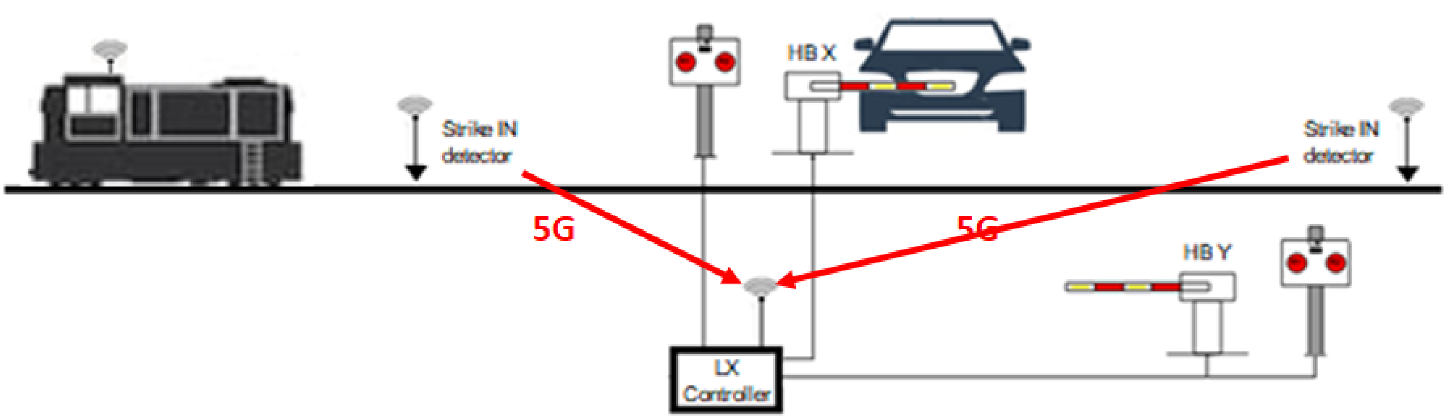

Figure 1

Safety Critical Communications

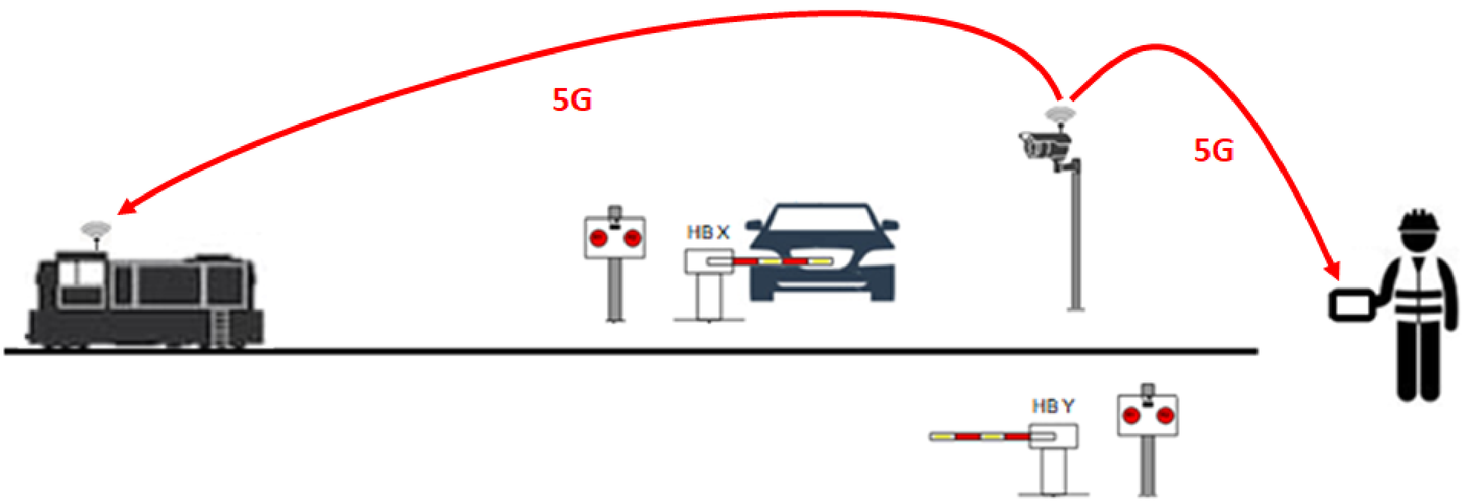

Figure 2

Non-Safety Critical Communications

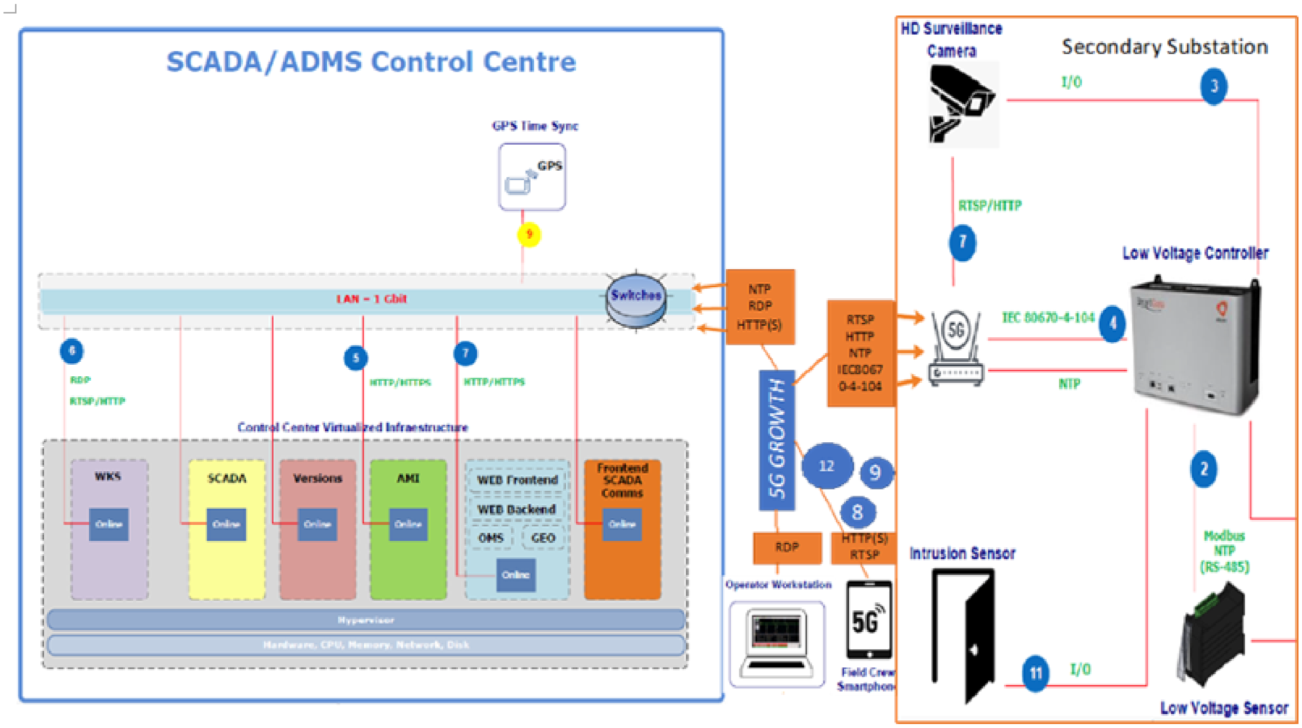

Figure 3

Advanced Monitoring and Maintenance Support for Secondary Substations MV/LV Distribution Substation

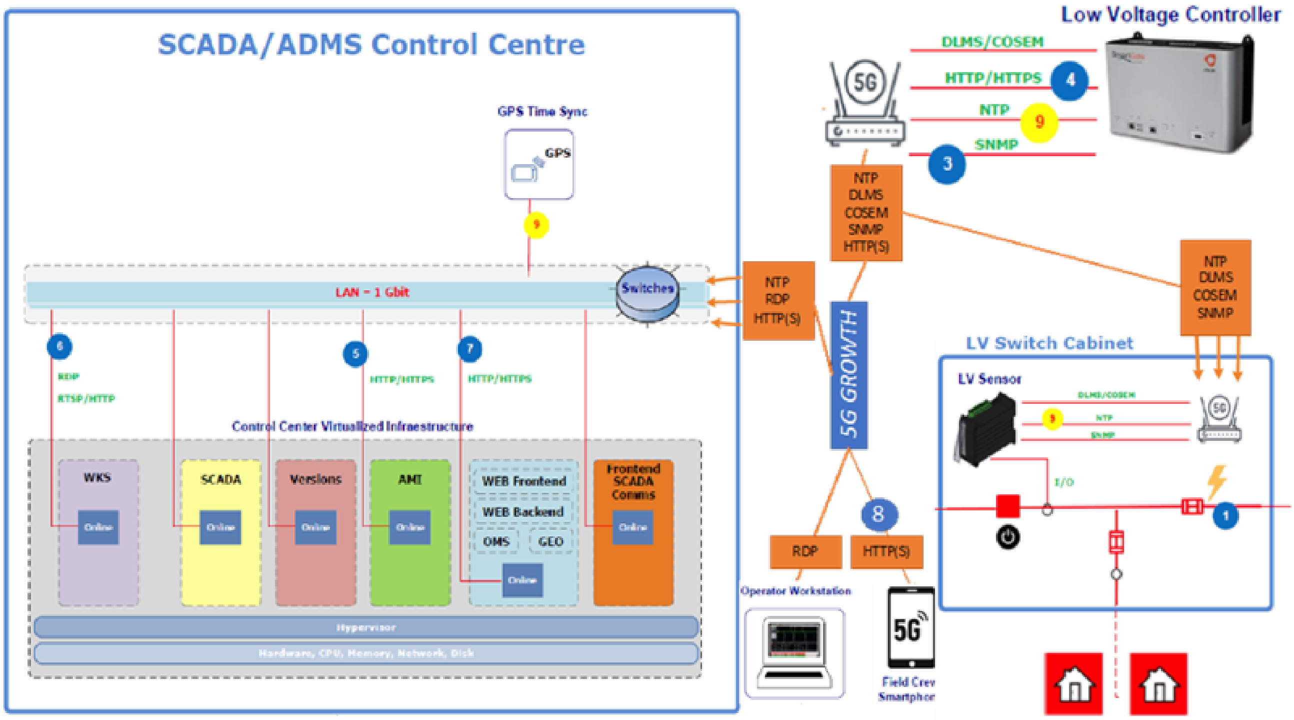

Figure 4

Advanced Critical Signal and Data Exchange Across Wide Smart Metering and Measurement Infrastructures