A Comparative Study of IoT-Communication Systems Cost Structure:
Initial Findings of Radio Access Networks Cost

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***Abstract*— This techno-economic study introduces a framework to study the deployment cost of IoT radio access network and to compare the cost and capacity of LPWAN, LPLAN, and Cellular-IoT systems. There are a plethora of Communication technologies available today. Small rollout and pilot projects are visible for most of the IoT connectivity technologies. However, The economic viability of cellular and non-cellular IoT connectivity technologies are not definite. The primary objective of this work is to analyze the cost structure of SigFox, LoRaWAN, NB-IoT, and WiFi-HaLow. In this paper, we study an urban scenario with the consideration of an Greenfield and Brownfield actor to understand the technology selection strategy of communication service prodvider's perspective. One of our findings indicates that the maintenance cost is the key cost driver for IoT radio access networks. We also point out certain bounds where a technology is potentially cost-effective.**

Keywords— Cost structure, LPWAN, Sigfox, Cellular-IoT, LoRaWAN, WiFi-HaLow.

I. INTRODUCTION

Recent market research anticipates an exponential growth of IoT services in the coming years [1]. Gartner estimates around 8 billion connected sensors and actuators have already been deployed by 2018, and we will be surrounded by 20 billion smart devices by the end of 2025 [2]. Because of the IoT services triggered information communication technology (ICT) transformation in all business verticals, IoT has been one of the most stimulating and featured topics in industry and research arena for the last seven years. IoT refers to the interconnections of devices like sensors and actuators which are remotely communicating with each other and the application server via wireless technology. Connected services range from smart-city services to smart factory and from smart home to healthcare. Car, cycle, refrigerator, name any apparatus and one can find a 'smart' version of the device in today's world.

Although there are opportunities for new sources of revenue from IoT services, the telecom market faces several new technological and business challenges along with many unanswered questions on economic viability. IoT services cannot be supported energy-efficiently and with robust-link coverage with existing wireless technologies like Bluetooth, Wi-Fi, LTE or GSM which are primarily developed for data and voice services. Many researches on technical and business challenges have been done to address the identified issues of IoT services. New connectivity paradigms, Low-power local area network (LPLAN), and Low-power wide-area network (LPWAN) have emerged to leverage the IoT services' incurred connectivity challenges. Technologies like Z-Wave, Dash-7, BLE, Zigbee, LoRa, 802.11ah, and 802.15.4k are developed to support short-range communications. On the other hand, SigFox, LoRaWAN, Weightless N/p, EC-GSM-IoT, LTE-M, NB-IoT are targeting long-range connectivity with robust coverage possibilities. Today, there are at least twenty connectivity solutions available in the market to meet IoT connectivity requirements [3].

It is not clear which IoT communication technology is the most cost-effective solution from IoT service provider and communication service providers' perspective. In the present, small rollout and pilot projects are visible for most of the IoT connectivity technologies. Studies related to Cellular network deployment cost can be found in the literature [4]-[12]. Although there are relatively many studies on business modeling [13]-[14]and value network[15]-[16], to the best of our knowledge, the economic viability of cellular and non-cellular IoT connectivity platforms are not well studied.

Hence, this paper focuses on the cost-structure and cost drivers of IoT connectivity service rollout. The objective of this paper is to make a comparative analysis of cellular and non-cellular wide area IoT technologies taking into account the service demand, deployment cost and the use of unlicensed and licensed bands. In this paper, we analyze the business case for deploying IoT connectivity services for a different level of smart sensors' activity cycles taking into account the possibility to reuse or rent existing base station sites. The overall question we address in this paper is:

What are the cost-effective scenarios and deployment strategies for the non-cellular and cellular IoT connectivity solutions?

To answer the question, we look into Smart City service cases. Out of many technologies, in this study, we compare NB-IoT, LoRaWAN, SigFox, and Wifi-HaLow to understand the feasible use-cases for each technology. The main contributions of this paper are: i) To understand the cost breakdown of IoT Connectivity solutions' deployment cost regarding CAPEX and OPEX, and ii) Categorizations of the viable business cases and deployment strategies for IoT connectivity solutions.

The paper outlines as follows; section II covers the related works; section III contains an overview of studied technologies. Section IV describes the research approach and assumptions followed by the results in section V. We present findings and discussions in section VI, and conclusions in section VII.

II. Related Work

Cellular network dimensioning and cost assessment is an intrinsic part of the techno-economic study to understand the cost-drivers of new technology. Usually, new service requirements have dominantly changed the network dimensioning methodology over time. For instance, the MBB service introduces the resource capacity dimensioning method for 3G and 4G networks [6]. Earlier studies [4]-[5] consider the cost structure of mobile systems and describe resource capacity and coverage of the radio interface as the dominant cost factors. Other works [7]-[10] have developed a techno-economic model to evaluate different heterogeneous radio networks cost and capacity. From these studies, it is clear that the heterogeneous network's cost structure dominate by two critical parameters: i) resource capacity and ii) coverage. Moreover, energy consumption for BS is included in the cost structure of [11]-[12]. The increasing adoption of IoT brings new challenges to traditional network capacity requirements. This brings the need to reevaluate the capacity constraints in the course of IoT-connectivity dimensioning.

III. Overview of Technologies

In this section, we discuss the specifications of technologies we have studied in this paper. Table I presents the specification of the technologies. We have collected the technology specifications based on a literature review [17], [18], [23] standardization specifications [19] [20] and white papers [21] [22]. The more details of the technologies are discussed below.

A. Sigfox

Sigfox is one of the most adapted LPWAN solutions that offer a complete end-to-end IoT connectivity solution in 60 different countries in the world. It is a proprietary ultra narrowband (UNB) technology that operates at 868MHz in Europe and 915 MHz in North America. Sigfox uses binary phase shift keying (BPSK) modulation in 100 Hz bandwidth. This gives a low noise level, which assures simple antenna design, low power consumption, at the transmitter side, high receiver sensitivity leading to large coverage area. However, due to the UNB, the large coverage and longer battery lifetime achieved with the compromise of data throughput. A Sigfox device can transmit at 100bps at the uplink in a half-duplex manner. Furthermore, due to regulation, limitation, Sigfox has a transmission limitation per device. A device can transmit 140 uplink messages per day where can receive only 8 downlink messages per day, which means the transmission works in a 'fire and forget' manner. However, a device repeats the same message three times in different time and frequency which reasonably assure the message delivery rate to 95%. The maximum payload size of a message in Sigfox is only 12 bytes with 14 bytes of overhead. The most important selling point for Sigfox is the single platform and OSS/BSS system to support all the operators in the world which means Sigfox can offer roaming free subscription in any of the operating countries. This also allows all the Sigfox operators to reduce the initial investment on the core networks.

TABLE I. Specifications of technologies.

	Sigfox	LoRa WAN	NB-IoT	WiFi-HaLow
Frequency Band (MHz)	868	868	868	900
Receiver Sensitivity (dbm)	164	154	150	146
Device Capacity/cell	100000	10000	150000	8191
Spectrum (kHz)	200	1175	180	1000
Modulation	D-BPSK	FSS/CSS	OFDMA	OFDMA
Sub-channel BW (Hz)	100	125000	15000	-
Spacing (kHz)	0	200	3.75	-
UL Payload (Bytes)	12	51	125	256
DL Payload (Bytes)	8	14	125	256
Data Rate (bps)	100	1760	50000	300000
Duty Cycle/ Tx Restriction	140 msg/day	1%-10%	-	2%
Bidirectional	Half Duplex	Half Duplex	Half Duplex	Full Duplex

B. LoRaWAN

LoRaWAN uses the physical layer technology of LoRa that modulates in the unlicensed SubGHz band using a proprietary chirp spread spectrum (CSS) techniques. LoRaWAN shares ISM Band 868 MHz in Europe and 915 MHz in North America along with Sigfox. However, LoRaWAN offers bi-directional transmission of a narrow-band signal over a wider channel bandwidth that results in transmission with low noise levels and high interference resilience. LoRaWAN uses six spreading factors (SF), SF7 to SF12, to address different deteriorate at different ranges. Lower spreading factor allows high data rate at the cost of shorter range and vice versa. Depending on the channel bandwidth and SF, LoRaWAN can offer throughput between 300bps to 50kbps. It can provide a maximum message size of 251 bytes [17]. Like Sigfox, LoRaWAN devices are independent of cell meaning all the neighboring cells receiving a signal, then the OSS/BSS reject the multiple messages. The Duplicate receptions improve the message delivery success rate. Furthermore, to meet a large portion of IoT application requirements, LoRaWAN offers three classes of devices. However, Due to the regulatory limitation on the usage of unlicensed band LoRAWAN also limits the end device usage in the mean of 1% duty cycle, which can be translated to 36sec/hour transmission per device on one channel. Unlike Sigfox, LoRaWAN does not offer any communication platform solution; rather it relies on open platform solutions which are still under development. Thus the small-scale deployment of the system can be seen in today's world.

C. NB-IoT

3GPP standardized narrowband-IoT (NB-IoT) on release-13 in June 2016. There are other two technologies released by 3GPP at the same time, eMTC (LTE Cat M1) enhance LTE, EC-GSM-IoT is designed to enhance GSM. However, NB-IoT can be considered as a new track based on the existing 3GPP technology specifications. An advantage of cellular solutions compared to other LPWAN technologies is that they do not have the duty cycle regulations, because of operating on licensed bands. In NB-IoT, new radio is added to the LTE platform to optimize the low end of the market[17]. The objectives of 3GPP to release NB-IoT is to give even lower cost than eMTC as well as extended coverage (164dB). NB-IoT can also support long battery lifetime (10 years) and a large number of devices (50000 per cell). It also provides some simplifications, such as reduced data rate/bandwidth, mobility support and further protocol optimizations. Also, NB-IoT supports a single transmission mode of SFBC for PBCH, PDSCH, PDCCH. 3GPP continuously enhancing the performance of NB-IoT in new releases. It is said to be extended to include localization methods, multicast services, mobility, etc in the future release [17]. NB-IoT can coexist with GSM and LTE's licensed band and also can operate in the 868 MHz band. NB-IoT occupies one resource block of LTE systems corresponds to 180kHz in the frequency band. There are two modes for uplink, one is single, while the other is multiple tones. NB-IoT is expected to be deployed with a simple software upgrade in addition to the existing LTE's radio system but not backward compatible.

D. *WiFi-HaLow (IEEE802.11.ah)*

The Wi-Fi Alliance introduced a new standard IEEE 802.11ah also known as WiFi-HaLow for IoT sensor communication with lower energy consumption and larger area coverage capacity. Many new MAC features are added to support a large number of sensor devices, an extended range of operation and less energy consumption compared to existing Wi-Fi standards [18]. As for the unique feature, WiFi-HaLow can support up to 8191 devices associated with an access point (AP). The new technology uses sub-GHz carrier frequencies and upto 1 km transmission range in outdoor areas. The data rates of WiFi-HaLow is higher than other LPWA technologies; it reaches at least 100 Kbps. It is a solution with very low energy consumption [23]. However, devices in the Sub-GHz bands must comply with the maximum duty cycle limit of 2.8% in Europe, provided that they also support Listen Before Talk (LBT) and Adaptive Frequency Agility (AFA) features [23]. In order to optimize long battery time and a large number of devices, some features were designed for WiFi-HaLow. It provides a short frame format, short control/management, asymmetric and bi-directional transmissions which are more efficient. WiFi-HaLow reduces the power consumption by target wake time (TWT) mechanism and extended sleeping and listen to the interval protocol [18].

IV. RESEARCH APPROACH AND ASSUMPTIONS

In this section, we describe the analytical approach, the assumptions and the scenario that is used in the analysis. We compare the cost-capacity characteristics of LPWAN, LPLAN and C-IoT systems. The analysis includes a network dimensioning part and a cost assumption and analysis part.

A. *Scenario Description*

We consider an urban city use case where smart city services are the key focus. We consider an urban city area of 100 km^2. We compare the costs for deployment and operation of networks using LPWAN and LPLAN access points with the cost of Cellular-IoT solutions. We both consider the cases of building new sites to roll out and sites to lease from another actor like telecom operators. The incumbent operator reuses the site they own to roll out such technology for IoT connectivity services. We only consider the sub-GHz band between 700Mhz-900MHz. For the cellular-IoT systems, we consider a stand-alone system that uses the unlicensed band.

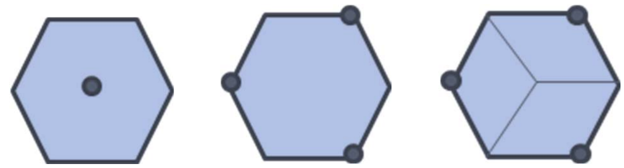


Figure 1. Three different types of sites (Omni directional, 3-RAT null-sector, Three-sector)

B. *Traffic Demand*

Unlike traditional data services, the IoT services consume a small amount of data sporadically. Which means the modeling of data usage per user and month may not always represent the appropriate boundary condition of an IoT communication system. We propose to include on-air usage per device and day along with the user per area unit and the data usage per users and day. This is converted to a required capacity per area unit ($\mathrm{Messages/km^2}$) for a service day. We consider Stockholm's population density, which is 3597 $\mathrm{People/km^2}$. We assume in the first year, only 5% of the population will have sensors and by the end of the year 10, the IoT device density will reach to 40 sensors per person. An incumbent operator will have 40% of market share. We assumed the sensors belong to the service set like the metering, monitoring and management services like Smart parking, waste management, city lighting, and apparently for vehicular communications.

C. *Network Dimensioning*

We consider key radio technologies from LPWAN, Cellular-IoT, and LPLAN; these are Sigfox and LoRaWAN, NB-IoT and WiFi-HaLow, respectively. The reason behind these technology selections was the coverage area, and in this case, we only considered technologies those have at least 1 km coverage range. We assume three sector site for SigFox, NB-IoT. Where for LoRaWAN and WiFi-Halow we only consider one cell scenario. To dimension the network, we consider the average capacity based heuristic dimensioning method.

Coverage and Capacity

We use a direct mapping of theoretical throughput and device capacity by considering appropriate link level capacity stated in [7] [9]. For the capacity dimensioning we consider three parameters:

1) *Device capacity (sensor devices per site):* the number of devices a radio station can support.

2) *Data capacity per site and day:* Data capacity for uplink is calculated as,

$$C_{Data} = N_{channels} * R_{data} * \left(1 - f_{degradation}\right) * N_{Sector} * t_s$$

Where, $N_{channels}$ is the number of channels allocated for uplink transmission, R_{data} is the max data rate can be obtained per channel, $f_{degradation}$ is the coefficient to determine the rate of data rate degradation, N_{Sector} is the number of sectors per site, t_s Is the time of a day in seconds which is 24h*3600s.

3) *Massage transmission capacity per site and day:* it can be calculated and 'time on air,'

$$C_{TxMsg} = \frac{C_{Data} * (1 - p_{cc}) * (1 - PER)}{Data\ Payload + Overhead}$$

Where p_{cc} is the percentage of resources allocated for the control channel and S_{Packet} is the packet success rate for a certain use case.

Additionally, due to the regulation restriction of device transmit on an unlicensed band, we also consider maximum device transmission allowed to perform a validity check that a service requirement can be by a specific technology set.

As depicted in figure 1, we noted three types of cell deployment strategies when it comes to cell coverage. To meet certain requirements, a particular strategy has been adopted by a specific technology set. The LoRaWAN and WiFi-HaLow usually have omnidirectional antennas where Sigfox considers three cell scenario, but there is no sector within a cell. In other words, if a device transmits a packet with all the nearby base stations will receive the packet and then forward it to the OSS/BSS and then it is BSS to decide which packet to keep and which to drop. So, This type of cell deployment is needed to increase the QoS and link availability and accessibility rate, but not affecting the overall data or message capacity of a cell. Cellular-IoT technologies, on the other hand, consider the sectorized cell which means an increment of sector increase the capacity and coverage performance.

TABLE II. COVERAGE AREA

	Urban	*Suburban*	*Rural*
Sigfox	*1,92*	*17,77*	*39,84*
LoRaWAN, SF=9	*0,67*	*8,34*	*21,83*
NB-IoT	*1,43*	*17,75*	*39,68*
WiFi-Halow	*0,40*	*0,918*	*1,558*

To estimate the cell range from the pathloss, we calculate the pathloss from the data specifications of receiver sensitivity, transmit power, antenna gain at the receiver and transmitter site that is specific to each technology. Then we use the Okumura-Hata propagation model for Urban outdoor to indoor attenuation and rural outdoor attenuation. The derived cell range of different technologies can be found in able in Table II. In this calculation, we consider all the sensor devices have an antenna gain of 3db, and the receiver antenna gain at the base station is set to 6db.

D. *Cost Structure Analysis*

In the calculation of the total network costs, CAPEX and OPEX elements directly linked to the RAN are considered. The cost assumption and key elements that we have considered in this paper are listed in Table III. The cost data presented here is taken from three main sources. We took the NB-IoT cost assumptions from METIS-II [17] [24]. SigFox, LoRa and WiFi-HaLow from [17] ,[7].

The net present value (NPV) analysis is applied to account for the investment and operation cost. In this study, we consider the discount rate is 10%. Future costs are, hence, discounted to present value and the NPV over N years is

TABLE III. COST ASSUMPTIONS

	Sigfox	*LoRa WAN*	*NB-IoT*	*WiFi-Harlow*
Equipment Cost (K€)	*4*	*1*	*3-10*	*1*
Installation Cost (K€)	*6*	*2*	*10*	*2*
Spectrum Cost (K€/kHz/site)	*0*	*0*	*0*	*0*
Site Build Cost (K€)	*10*	*2*	*20*	*1*
Transmission Installation Cost (K€)	*0,5*	*1*	*0*	*1*
Site Lease (K€/year)	*1-8*	*0,4-1*	*0-8*	*0,4-1*
Electricity Cost (K€/year)	*1*	*1*	*1*	*0,1*
Transmission Cost (K€/year)	*0,12*	*0,1*	*0,1*	*0,1*
Operation & Maintenance Cost (relative to CAPEX)	*15%*	*15%*	*10%*	*25%*

$$NPV = \sum_{y=0}^{N} \frac{C_y}{(1+r)^y}$$

Where, C_y represents the annual total cash flow in year y, while r represents the discount rate, y represents the network operation period in years, and n represents the number of base station required. In the NPV analysis, we consider an average revenue per device is 70 euro per year with a 5% depreciation of each year. Also, we assumed that the OPEX and maintenance cost is increasing 5% each year.

TABLE IV. RE-USEABLE SITES

	Sigfox	**LoRa WAN**	**NB-IoT**	**WiFi-HaLow**
BS Range (km)	1,99	0,67	1,43	0,40
Re-useable sites	20	39	26	77

V. COST ANALYSIS

The results presented in this section assume investments and maintenance for 10 years with zero interest rate. We consider the urban smart city scenario of Sweden. We assume that the CAGR of penetration rate would be 57% in all default cases. We have considered the devices activity rate and payload size to 5 messages/ day and 12 bytes of payload per message in a low intensity of traffic. For the high traffic intensity, we consider the device density is 40 times the population density, and the sensors transmit more frequently like 300 messages/day, and each message is 300 bytes long. Figure 2 illustrates an example of the CAPEX and OPEX cost breakdown for site build and leasing for a new market entrant case. We have considered the network equipment, installation, and planning, transmission installation, spectrum, and site-building or leasing costs as part of CAPEX. For the OPEX, we have considered power, site lease, along with operation and maintenance cost.

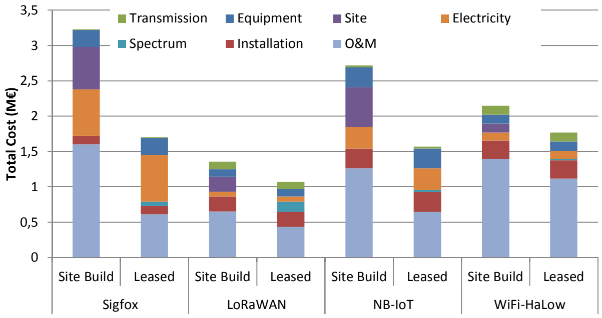


Figure 2. Example of cost of own site vs. leasing for new market entrant case in low device density and low traffic intensity with device penetration rate to 5%, and CAGR to 57%.

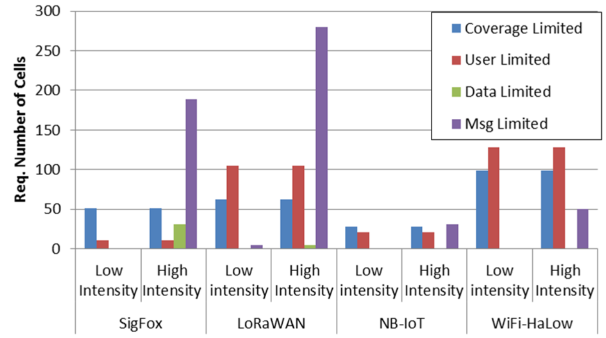


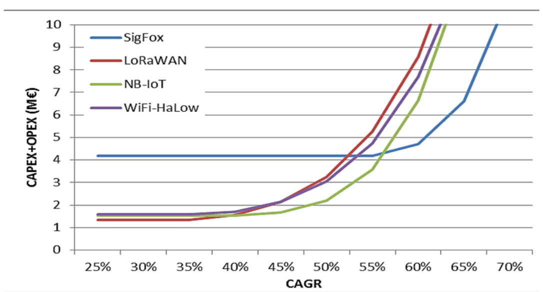
Figure 3. Traffic intensity to required number of base station/Access point

Before going into the details of the cost results, we would like to illustrate the dimensioning limitations of each technology depicting in figure 3. The horizontal axis represents the traffic intensity, and the vertical axis represents the requirements of the cell. As we can see, Sigfox is coverage limited to the low traffic case when the devices are sending only 12 bytes of data periodically every hour. However, this technology is message limited for high intensity of traffic considering denser deploying sensors that transmit as frequent as every 10 minutes. For the same assumptions, LoRaWAN is limited either to devices or data in low intensity and high intensity of traffic, respectively. NB-IoT is coverage and marginally message limited, and WiFi-HaLow has always been device limited in both traffic demand cases.

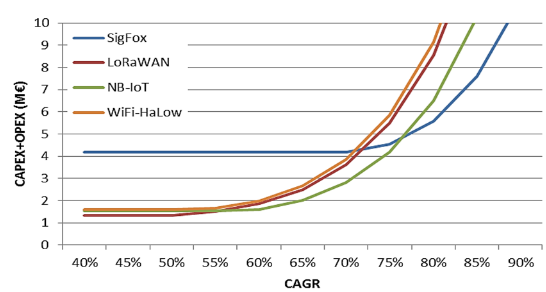
For the cost analysis, we have analyzed the cost from two perspectives:

i) The CAGR to cost: as most of the base stations are device limited, this gives an understanding of the deployment feasibility at specific device growth;
ii) Activity interval to cost: represents how must cost is subjected to meeting a certain service activity ratio. In this study, we have presented an average activity interval of devices to cost relationship.

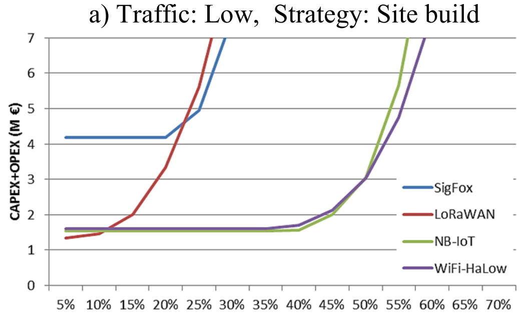
Figure 4 shows the CAGR to cost relationships for an incumbent actor case. For the incumbent operator case, we assume that the operator has existing sites to reuse and it is assumed the inter-site distance of the site in an urban area for the cellular operator is 500m. Naturally, due to the design bout, all the existing cellular sites are not reusable. Table IV illustrates the number of sites each technology can reuse. Also, we assume that first, the actor will use their existing sites to meet the demand then for the new sites the actors will be encountered site build, transmission, and power cost. As we can see, for three ranges of growth rate, namely lower growth rate, medium growth rate, and higher growth rate three technologies LoRaWAN, NB-IoT and SigFox are beneficial to deploy, respectively. We can observe a similar trend in high traffic and leasing case as well. However, when it comes to deploy own site Wifi-Halow potentially can achieve the lowest deployment cost than others provided that the site build cost is lower than Sigfox and cellular systems. Figure 5 demonstrates a similar relationship and tends for greenfield scenarios as well.



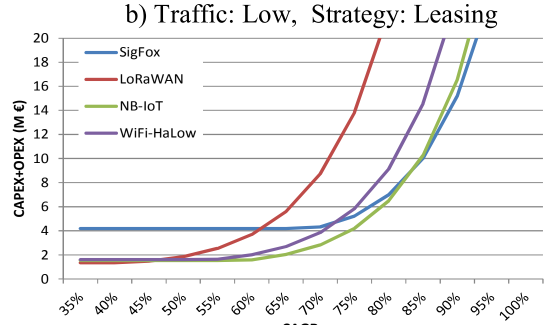
a) Traffic: Low, Strategy: Site build



b) Traffic: Low, Strategy: Leasing

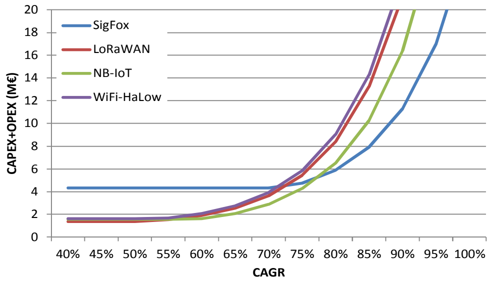


c) Traffic: High, Strategy: Site build

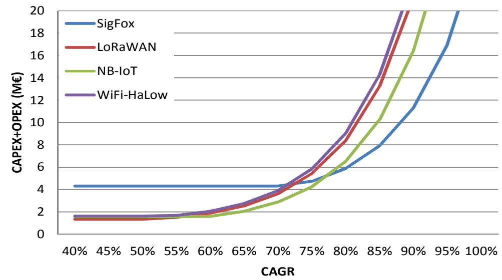


d) Traffic: High, Strategy: Leasing

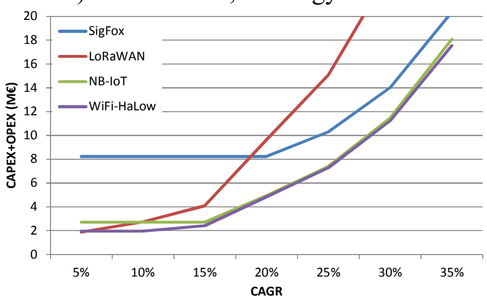
Figure 4. Incumbent actor Scenario



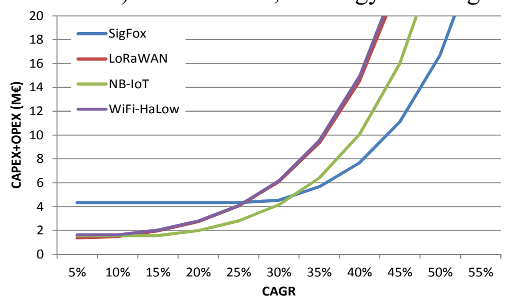
a) Traffic: Low, Strategy: Site build



b) Traffic: Low, Strategy: Leasing



c) Traffic: High, Strategy: Site build



d) Traffic: High, Strategy: Leasing

Figure 5. Greenfield Scenario

In this scenario, we have considered the actor is a new market entrant and will deploy a network from scratch.

Figure 6 illustrated the activity interval to cost implications. The device activity interval does not affect the cost function until the activity interval decreases to the minute interval. Then the cost exponentially increases. Mainly due to the limited capacity and longer transmission time we see LoRaWAN to saturate at 10 min activity interval, and then Sigfox and NB-IOT reach the saturation when it is about support five mins activity interval. WiFi-HaLow with its large data capacity and shorter message transmission time can support up to every minute activity without breaking the cost limits.

Figure 7 illustrates the NPV of low-intensity traffic. The NPV analysis has been done for 10 years, assuming that the investments are made in the year 1 with a discount rate of 10% and ARPU per users is 70 Euro with 5% erosion per year.

VI. Discussion and Findings

In the analysis, we have only considered urban area cases where the coverage area is 100 km^2. We have seen both incumbent and greenfield deployment cases. As the incumbent operators can re-use some existing sites, with the same amount of deployment cost, they can target a more significant growth rate than Greenfield operators. Also, Greenfield operators need to invest in creating a marketing channel and brand value which undoubtedly will play an impact on the overall cost, however, are not included in this analysis.

As illustrated in Table III, LoRaWAN has lower site installation and building cost for urban cases along with WiFi-HaLow. As a result, if a market entrant decides to deploy the network from scratch, LoRaWAN is beneficial for small actors who target a smaller market share. This is also true for the incumbent operator case with low traffic intensity. In both Incumbent and Greenfield scenarios with leasing we see LoRAWAN, NB-IoT and Sigfox are cost-efficient for the small, medium and large density of devices, respectively. However, if an operator wants to roll out, targeting high-intensity traffic, according to our analysis, Wifi-HaLow is the prominent solution. This is mostly because of the large capacity of WiFi-HaLow with low deployment cost. Overall, we can say that the deployment cost of IoT communication technology can be proportionately mapped to the user density supported by a technology.

Message intensity to cost relation can imply the limit up to tat an operator does not need any additional invest on radio deployments. If the message generation of existing service changes over the years with this type of analysis, we can assume the activity interval tolerance limit of certain technology. Indeed, this gives a degree of freedom to the service providers as well, as they can fine tune and can achieve more granularity over the collected data.

As known from the cost assessment of cellular systems, site leasing is more beneficial than site building in all the cases. It is interesting to note that the site leasing and building strategy may influence the technology selection decision of an operator as depicted in figure 2. The site building, and operation and maintenance costs are the cost drivers for IoT communication technologies.

Above findings have direct implications on the business strategies. Users prediction is a vital factor For any business projections. As users prediction also implies the target of a company and the companies vision about the market position. Using our analysis framework one can choose the cost-effective technology that meets the company vision about the market share. Also, this technology selection gives a selection of service segment that an actor can target with a specific set of technology. Furthermore, the IoT service provider can use this type of analysis to understand the service scalability a certain technology can offer. Hence, can assure cost-efficient scalability through their service offerings.

Please note that, in this study, we did not consider the core network server, communication platform, service platform and device cost. Considering these factors may potentially change the NPV analysis of IoT communication systems.

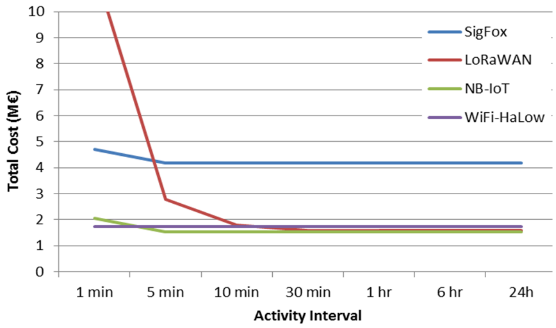


Figure 6. Devices average activity interval to cost

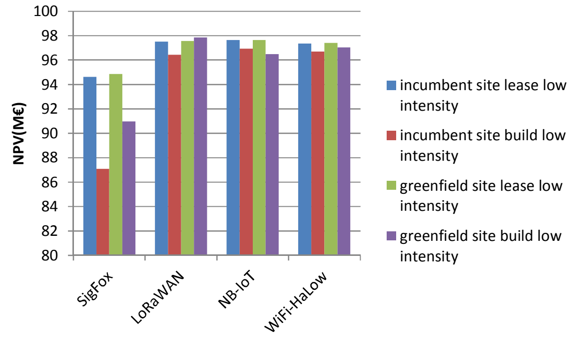


Figure 7. NPV

VII. Conclusions

A plethora of IoT communication technologies available today. However, It is not sure how scalable and cost-effective the solutions are and in which condition the solutions are vable for business actors. In this paper, we have studied the cost-capacity performance of LPWAN, LPLAN and Cellular-IoT deployment in unlicensed band. For the first time, We introduces a framework to study the deployment cost of the IoT radio access network. Our study suggests that for the low device growth rate with infrequent message transmission LoRaWAN is the most economically viable solution among the four considered technologies. Furthermore, NB-IoT is cost-efficient for average growth rate of the sensors, and for high growth rate, SigFox is the cost-effective solution. Moreover, one of our findings suggests that the device activity rate has a direct link to the radio deployment cost. Another key outcome of this study indicates that the operation and maintenance cost is the key cost driver of IoT-communication technologies followed by the base station site cost. Hence, we can say new site building or leasing still can influence the technology selection decisions. For instance, if a new operator target to provide video surveillance type services, scratch deployment of WiFi-HaLow is beneficial than other technologies even though the operation cost for WiFi-HaLow may be as high as 25% of the CAPEX. As for future study, one should look into the platform and the core networks cost to get a detailed understanding of the cost driver.

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