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Design of an NB-IoT Smart Metering solution: Coverage and capacity planning: Case of Yaoundé and Douala

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ABSTRACT

Advances in technology over the years have enabled the Internet of Things to seize the untapped opportunities of information and communication technologies. NB-IoT, one of the LPWA technologies, is attracting a lot of attention of universities and telecommunications companies. This technology, standardized by 3GPP in June 2016, offers advantages such as faster and simpler deployment using the existing cellular network, a large coverage area, low cost and low power consumption. It has great potential to meet the enormous demand for machine type communication in the age of the Internet of Things. The smart meter is an application that potentially uses NB-IoT technology for water and energy management. In the water and energy sector, the reading of water and electricity consumption is done manually especially in country like Cameroon. The meter reader staff enters individuals' homes or businesses and reads the meters. Under these conditions, a rigorous and regular reading of meter indices proves to be restrictive, costly and even impossible; and there is a big possibility for spreading COVID 19 virus. This process poses a problem, of bills that do not correspond to actual consumption. This research document proposes an innovative solution to this societal problem, a smart meter based on NB-IoT. This study aims to analyze the planning of NB-IoT network in terms of coverage and capacity by relying on an LTE network in 1800MHz band. The results of the calculations show that the number of sites required is different both in terms of coverage and capacity, and the highest number of sites has been taken to meet the requirements. Thus, the number of sites required is 19 for the city of Douala and 17 for the city of Yaoundé. The initial results obtained in this work are acceptable and encouraging.

General Terms

NB-IoT smart metering.

Keywords

Narrowband, IoT, NB-IoT, MTC, LPWA, Smart Meter.

1. INTRODUCTION

The Internet of Things is a global infrastructure for the information society enabling advanced services by interconnecting objects (physical and virtual) based on existing and evolving interoperable information and communication technologies [1]. It is expected that IoT will manage the gigantic network of billions of devices to provide many intelligent services to users. From the transmission rate point of view, IoT communication services can be classified into two categories: high-speed services (such as video service) and low-speed services (such as counters) [2]. According to statistics from ATECH in 2017, narrowband services account for more than 67% of total IoT services, indicating that LPWAN technologies are really desirable especially NB-IoT.

Narrowband Internet of Things is a Low Power Wide Area technology proposed by 3GPP for the perception and acquisition of data for intelligent applications at low bandwidth. Smart metering is an application that potentially uses NB-IoT technology for water and energy management, which is expected to be implemented massively in the near future.

The current system for recording the consumption indexes of water and electricity meters in Cameroon presents a serious problem, namely that of bills that do not correspond to actual consumption. The planning analysis was performed by examining NB-IoT technology as a connectivity technology used to support smart meter service. The cities of Yaoundé and Douala are dense urban areas. It is necessary to analyze the minimum number of eNodeBs required from coverage and capacity sizing to implement the NB-IoT network of smart meter services for the two regions.

This document consists of several sections explaining the NB-IoT network planning analysis for smart meter services. Section 1 is an introduction and explanation of the planning context. Section 2 describes the NB-IoT technology. Section 3 describes the methodology used for coverage and capacity, and Section 4 presents the results. Finally, the last section, Section 5, presents the conclusions of the study.

2. NB-IoT TECHNOLOGY

2.1 Definition and requirements

Since 2005, 3GPP has started extensive research on cellular networks (such as GSM, UMTS and LTE) for machine type communication services. NB-IoT is designed to connect a large number of devices in a wide range of application areas forming what is called the Internet of Things. Connected objects must communicate through an existing cellular infrastructure. 3GPP has also introduced different data rates suitable for narrowband IoT, ranging from a few tens of Kbps in 180 KHz bandwidth (LTE Cat-NB1) to a few hundred Kbps [3, 4]. The NB-IoT is a low-power wide area network solution that operates in licensed frequency bands. 3GPP includes this technology in the LTE standards in order to benefit from the large ecosystem offered by LTE technology and mobile operators.

NB-IoT devices are designed with the following requirements and objectives:

- Massive low-bandwidth device count: Support for at least 52,547 connected devices in a cell site area. This target is based on the use of 40 devices per household, with household density based on the City of London assumption provided in [5, 6] (density of 1517 households per km2 and distance between cell sites of 1732 m);
- Low power consumption: allow IoT devices to draw a low current (on the order of a nanoampere) to make it possible to charge a single battery for several years (on the order of 10 years);
- Longer battery life: the goal is to offer a 10-year battery life with a capacity of 5 Wh;
- Improvement of indoor and outdoor coverage: the objective is to obtain an extended coverage of 20 dB compared to cellular networks and other technologies. A data rate of at least 160 bps should be supported for both uplink and downlink ;
- Low complexity: the goal is to provide ultra-low complexity devices to support IoT applications, resulting in lower cost;
- Low latency: latency of 10s or less is the target for 99% of devices;
- Low cost: a cost of 5 USD per device. NB-IoT devices are connected to the infrastructure and the cellular network.

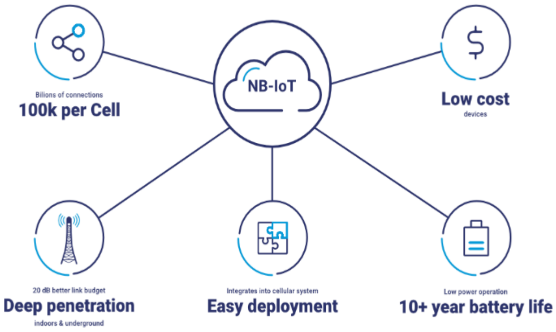


Figure 1: Advantages of NB-IoT.[15]

2.2 NB-IoT network architecture

Figure 2 shows the architecture of NB-IoT network, which consists of five parts, namely NB-IoT device (things), NB-IoT radio access, Evolve Packet Core (EPC) network, NB-platform IoT and application server.

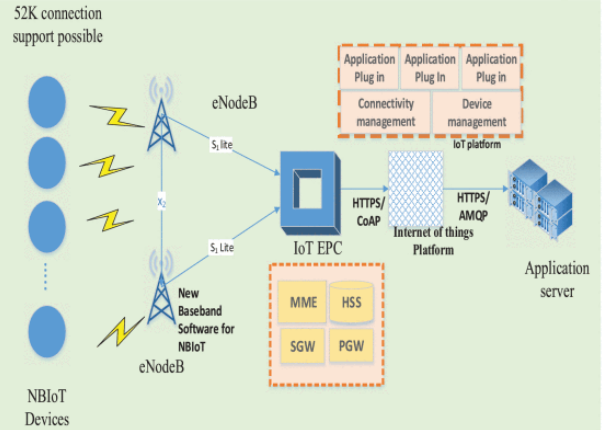


Figure 2: NB-IoT network architecture [7].

2.3 NB-IoT frequency bands

3GPP has defined a set of frequency bands for which NB-IoT can be used. Here is an overview of the supported frequency bands in the different regions [8]:

- **North America :** B4 (1700), B12 (700), B66 (1700), B71 (600), B26 (850) ;
- **Asie-Pacifique :** B1 (2100), B3 (1800), B5 (850), B8 (900), B18 (850), B20 (800), B26 (850) et B28 (700) ;
- **Europe :** B3 (1800), B8 (900) et B20 (800) ;
- **Latine America :** B2 (1900), B3 (1800), B5 (850) et B28 (700) ;
- **Commonwealth of Independent States :** B3 (1800), B8 (900) et B20 (800) ;
- **Sub-Saharan Africa:** B3 (1800) et B8 (900) ;
- **Middle East and North Africa :** B8 (900) et B20 (800) ;

These bands are only a subset of the bands supported by 3GPP. Version 13 is likely to be used: a total of thirteen frequency bands (1, 2, 3, 4, 5, 8, 12, 18, 20, 26, 28, 66 and 71). After looking at the minimum band overlap for different countries, it is estimated that a minimum of ten bands are needed: 1, 2, 3, 4, 5, 8, 12, 20, 26 and 28 are needed for coverage in every country.

2.4 Deployment mode

According to 3GPP specifications, there are three different deployment scenarios: **Standalone**, the 200 KHz bandwidth is used independently for NB-IoT outside of LTE; **Guard Band**, a bandwidth of 200 KHz is allocated in the guard part of LTE; **In-Band**, the 180 KHz bandwidth is occupied by LTE.

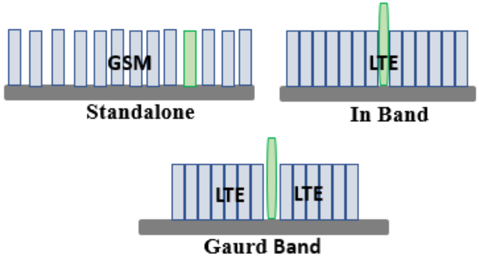


Figure 3: NB-IoT network deployment mode

3. METHODOLOGY

3.1 Planning

3.1.1 Definition

Planning is a process that aims to predict the evolution of demand in terms of number of subscribers, the volume of traffic induced by category of subscribers, the equipment necessary for its routing under defined security conditions and quality of service. This is an essential operation for the deployment of a network.

3.1.2 Planning process

IoT networks and services are very different from "classic cellular networks" in many aspects and especially from a planning point of view. The following diagram presents the planning procedure for a NB-IoT network.

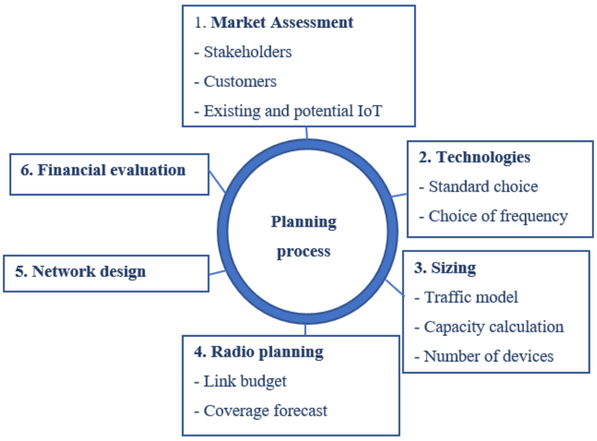


Figure 4: planning process of a NB-IoT network.

3.1.3 IoT Specificities and impacts on planning

The specificities of IoT technologies have impacts on network planning and design. IoT networks have different characteristics from those of traditional cellular networks. These characteristics have an impact on planning and design:

- ❖ Low power and large range

Gateways and terminals have high sensitivity. The use of low frequencies implies strong signal penetration. The use of narrowband allows a much greater reception range.

- ❖ Low deployment and running costs

The cost of gateways is low. 3GPP standards use existing mobile networks. Therefore, the cost is low. A wide range provides a large coverage area plus strong penetration (inside buildings). We have a small number of sites or gateways. The battery has a long life (100mA Rx current 100nA standby current). Because most of the time, the device is in standby mode and in connected mode only for transmission.

- ❖ Shared spectrum, interference management

This feature makes it possible to clearly evaluate the channels. Frequency hopping and OFDMA/CDMA access and NOMA technology help eliminate interference.

- ❖ Diversity of services

We have the diversity of traffic patterns and the diversity of transmission modes.

- ❖ Low speeds, simple topology

Sharing the infrastructure of existing cellular networks simplifies coverage of large areas. Having a low throughput (hundreds to thousands of bits/sec) implies a reduced number of gateways.

In the rest of our work, we will focus our attention on the third and fourth phase of the planning process, namely dimensioning as presented in figure 4.

3.2 Network dimensioning

3.2.1 Principle

In general, the dimensioning of mobile radio networks is carried out according to the steps below:

- Traffic/data analysis;
- Estimation of coverage;
- Capacity assessment.

Cell dimensioning requires fundamental data and parameters. These parameters include subscribers population, traffic distribution, geographic area to be covered, frequency band, allocated bandwidth, and coverage and capacity requirements. The system-specific parameters such as the transmission power of the antennas, their gains, the estimation of the system losses, the type of antenna system used, must also be known, before the start of the dimensioning, because each network without thread has its own set of parameters. Propagation models should be selected and modified if necessary, depending on the area and frequency band. All These are needed to estimate coverage.

3.3 Coverage dimensioning

Coverage of an area is ensured by a base station (BS). Therefore, it is essential to determine the number of BS needed to fully coverage requirements of an area, in order to avoid access failure, communication failure and reduce the handover rate. To do this, a link budget should be done.

Coverage planning procedure is presented by the following figure.

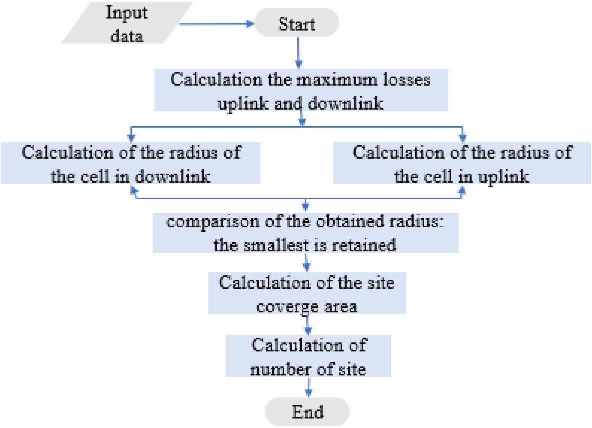


Figure 5: Coverage planning procedure [9].

3.3.1 Link budget

The link budget allows to calculate the maximum allowable path loss of a radio waves when it moves from one point to another. Through the maximum allowable path loss combine with an appropriate propagation model, the coverage radius can be deducted. The input parameters required for the link budget are: transmission power for the transmitter and receiver, transmitter and receiver gains, cable losses, interference margins and receiver sensitivity of both ends. In a mobile radio network, the radio link is two-way: Uplink and Downlink. This justifies the need to establish a link budget for both directions. However, whatever the direction of the link, the expression of the link budget remains the same, the main difference residing at the level of the transmitter and the receiver, and consequently of the characteristics of each. A radio link can indeed be illustrated by the figure below.

Figure 6: Link budget illustration

The following equation gives the mathematical formula of a link budget. [10] (from standard TS 38.901 of 3GPP).

- **For the Downlink :**

$$P_{(RX)DL,dBm} = P_{(SC)dBm} + Antenna\ Gain_{eNB} - Cable\ Loss_{eNB} + Antenna\ gain_{UE} - Cable\ Loss_{UE} - Path\ Loss_{propagation\ model} - Penetration\ Loss - Interference\ Margin - Slow\ Fading$$

Where:

$$P_{(SC)dBm} = P_{(TX)dBm} - 10.\log_{10}(N_{Sub\ carriers}) \quad Eq.1$$

- **For the Uplink :**

$$P_{(RX)UL,dBm} = P_{(UE)dBm} + Antenna\ Gain_{eNB} - Cable\ Loss_{eNB} + Antenna\ gain_{UE} - Cable\ Loss_{UE} - Path\ Loss_{propagation\ model} - Penetration\ Loss - Interference\ Margin - Slow\ Fading \quad \text{Eq.2}$$

Let assume that: $TPL = Path\ Loss_{Propagation\ Model} + Penetration\ Loss + Interference\ margin + SlowFading + Cable\ Loss_{eNB} + Cable\ Loss_{UE}$ Eq.3

The link budget equation becomes:

$$P_{(RX)DL,dBm} = P_{(SC),dBm} + Antenna\ Gain_{eNB} + Antenna\ Gain_{UE} - TPL \quad \text{Eq.4}$$

$$P_{(RX)UL,dBm} = P_{(UE),dBm} + Antenna\ Gain_{UE} + Antenna\ Gain_{eNB} - TPL \quad \text{Eq.5}$$

Where:

P_{RX}: Received signal;
P_{TX}: BS transmitting power;
P_{SC}: sub carrier power;
Subcarrier Quantity: This parameter designates the number of sub-carriers used. It depends on the number of RBs used and the configuration of the subcarrier. It can be calculated by the formula:

$$Number_{sub-carriers} = Number_{RB\ used} \times Number_{sub-carriers\ per\ RB} \quad \text{Eq.6}$$

TPL: represents the total loss on the path (BTS to UE);
Antenna Gain: represents the antenna gain;
Path Loss: is the maximal allowable path loss;
Penetration Loss: represents the penetration losses;
In fact, the penetration losses are model by the following formula according to authors in [18]:

$$PL_{Penetration,O2I} = PL_b + PL_{tw} + PL_{in} + N(0, \sigma_P^2) \quad \text{Eq. 7}$$

Where :

PL_b : is the path loss ;
PL_{tw} : loss due to the penetration inside a building from an external wall;
PL_{in} : is the loss inside the building depending of the building size ;
σ: is the standard deviation of the penetration loss.

- **Receiver sensitivity**

Receiver sensitivity is a measure of the minimum signal strength that a receiver can detect. It tells us the weakest signal that a receiver will be able to identify and process. In other words, it is the minimum power below which the quality of the link is degraded. It corresponds to a propagation with maximum losses. We should always have $P_{(RX)DL,dBm} \geq S_{(RX)DL,dBm}$. At the reception threshold, the received power is equal to the sensitivity and the Path loss become the Maximum allowable path loss (MAPL)
Therefore, the expression for the radio link budget becomes:

$$S_{(RX)DL,dBm} = P_{(SC),dBm} + Antenna\ Gain_{eNB} + Antenna\ Gain_{UE} - TPL_{DL} \quad \text{Eq.8}$$

$$S_{(RX)UL,dBm} = P_{(UE),dBm} + Antenna\ Gain_{UE} + Antenna\ Gain_{eNB} - TPL_{UL} \quad \text{Eq.9}$$

And the MAPL is: Where MAPL is the Maximum Allowable Path loss of the link.
Then we have:

$$MAPL = P_{(SC)dBm} + Antenna\ Gain_{eNB} - Cable\ Loss_{eNB} + Antenna\ gain_{UE} - Cable\ Loss_{UE} - Penetration\ Loss - Interference\ Margin - Slow\ Fading - S_{(RX)DL,dBm} \quad \text{Eq.10}$$

Indeed, the sensitivity depends on a set of parameters including the thermal noise power at the receiver, the noise factor and the SNIR. Depending on these parameters, the expression of the receiver sensitivity is given below

$$S_{RX} = Figure\ Noise + Termal\ noise + SINR \quad \text{Eq. 11}$$

The noise figure depends on the frequency band, the duplex gap and the allocated bandwidth. It is a parameter specific to each manufacturer. The SINR, just like the noise factor, is a parameter specific to each manufacturer.

3.3.2 Cell coverage radius calculation

From the link budget, we can have the MAPL, this MAPL at the edge of the reception is equal to the propagation model evaluate through a propagation model equation.

$$MAPL = Path\ Loss(d)_{Propagation\ Model} \quad Eq.12$$

The path loss itself is a function of the distance between the BTS and the user equipment, the path los scan also be written on the form

$$Path\ Loss(d)_{Propagation\ Model} = A + Blog(d) \quad Eq.13$$

3.3.3 *Propagation model*

The propagation model is used to estimate the loss during propagation of the radio wave caused by terrain and man-made environments. The propagation model is the foundation of coverage planning. A good model means more accurate planning. The propagation pattern depends on the allocated frequency of the system. Different propagation patterns have different allocated frequency ranges. It is important to note that the propagation patterns depend on the type of area. There are four types of areas commonly used in network planning: dense urban, urban, suburban and rural. Moreover, an indoor propagation model differs from an outdoor propagation model. The different existing propagation models are: the COST231-Hata model, the Okumura-Hata model, the K-factor or SPM model, etc.

A propagation model can be optimized to be more precise for specific town or environment, authors have proposed many methods for propagation model optimization in [16] [17] [18] [19].

In this work, we will use the basic COST231-Hata propagation model, because the NB-IoT desired network to be plan should operate at 1800MHz spectrum where in Cameroon all existing operators have deploy 4G LTE network.

This model is applicable for macro cell predictions when the frequency range is between 1500 to 2000 MHz. The formula for this model is given by:

$$L = 46.3 + 33.9\,log(f) - 13.82\,log(h_b) + (44.9 - 6.55 log h_b)\,log(d) - A(hm) + C \qquad \text{Eq. 14}$$

C=3dB for big cities and **C=3dB** for small or medium cities or suburban areas and

$$A(hm) = (1.1 log f - 0.7)hm - (1.56 log f - 0.8) \qquad \text{Eq.15}$$

3.3.4 Cell surface calculation

Using the above equations, we can have:

$$MAPL = A + Blog(R) \qquad Eq.16$$

That is:

$$R = 10^{\frac{MAPL-A}{B}},\ R\ in\ Km \qquad Eq.17$$

Following the coverage planning process, we must calculate the radii in UL and DL, and retain only the smallest value. It is this which corresponds to the optimum radius of the cell. Already knowing the radius of coverage, we can determine the surface of the target area for trisector cell as follows:

$$Area_{eNB} = 9\frac{\sqrt{3}}{8} * R^2 \approx 1.95 * R^2 \qquad \text{Eq. 18}$$

Thus, knowing the total surface of the zone to be covered, it is possible to determine the number of BS, noted N_{eNB}, necessary to ensure this coverage.

$$N_{eNB} = \frac{\text{Total Surface}}{Area_{eNB}} \qquad \text{Eq. 19}$$

3.3.5 Practical case of coverage dimensioning

The dimensioning will be done for 02 main towns of Cameroon, namely Yaoundé and Douala. Administratively, Cameroon now has ten regions, themselves divided into 58 departments. Yaoundé, is a city with seven hills, it is the political capital of the country is populated by 4,100,000 inhabitants in 2019, the city of Yaoundé is located between 3° 52' north latitude and 11°31' east longitude. This city covers an area of 183 km2. Douala is a port city in Central Africa on the Wouri River estuary open to the Gulf of Guinea. The city of Douala is located between 4° 03' north latitude and 9° 42' east longitude. Its agglomeration has 3.7 million inhabitants (2019 estimate), it is the economic capital of Cameroon, the main business center of the country. It covers an area of 210 km2. Yaoundé and Douala are the two largest cities in the country. According to the National Institute of Statistics, the estimated number of households is 3,255,651 in the city of Yaoundé and 3,322,170 in the city of Douala, with a density of households per km2 of 17,790 and 15,820 respectively. . Table 2 shows that planning the coverage of an NB-IoT network in the cities of Yaoundé and Douala leads to obtaining a number of eNodeBs in each city.

Table 1 : Coverage dimensioning result.

Parameters	DL (NPDSCH)	UL (NPUSCH)
Bandwidth LTE (MHz)	20	
Bandwidth NB-IoT (kHz)	180	
Frequency of carrier (MHz)	1800	
Number of resources Block	1RB	
Number of subcarriers	12 SC	
Bandwidth subcarrier (Hz)	15000	
Area of the Yaoundé city (Km^2)	183	
Area of the Douala city (Km^2)	210	
Transmitter	Tx = eNB	Tx = UE
(a) Total power (dBm)	46	23
(b) Power for NB-IoT(dBm)	35	23
(c) Antenna gain Tx(dBi)	18	0
(d) Cable loss Tx(dB)	-0.5	0
(e) PIRE	**52.5**	**40.5**
Receiver	Rx-UE	Rx-eNB
(f) Receiver noise factor (dB)	5	3
(g) Thermal noise (dBm/Hz) = -174+10log (15000)	-132.24	
(h) SINR (dB)	-12	-12
(i) **Receiver sensibility (dB) = (f)+ (g)+ (h)**	**-139.24**	**-141.24**
(j) Antenna gain Rx(dBi)	0	18
(k) Cable loss Rx(dB)	0	-0.5
(l) Interference margin(dB)	0	
(m) Penetration loss (dB)	-20	
(n) Shadow fading(dB)	-9.48	
MAPL (dB) = (e) - (i)+ (m)+ (n)	162.26 /**152.26**	
Propagation model	COST231-Hata	
Antenna heigh eNB(m)	30	
Antenna heigh UE (m)	1.5	
Ahu	0.04	
MAPL = A + B log(R) Avec A = 139.20 et B = 35.22		
Cell radius (Km) = $10^{\frac{MAPL-A}{B}}$	4.52	**2.35**
Area of a tri-sector cell (Km^2) = $1.95*R^2$	39.84	10.77
Number of sites in Yaoundé	**17**	
Number of sites in Douala	**19**	

From this planning we can see that respectively for Yaoundé and Douala, 17 and 19 NB-IoT sites could be enough to provide a smart metering solution which can include electricity, water and gas. In the next section, we will discuss about capacity planning in NB-IoT applied to the case of Yaoundé.

3.4 Capacity planning

For NB-IoT network capacity planning, we have two procedures.

3.4.1 First Procedure

During the initial feasibility study of NB-IoT in 3GPP version 13, the goal was to design a system capable of supporting a load of 60,680 devices per km2 [12]. Later, in version 14, it was decided that NB-IoT should also meet the 5G requirement for connection density of 1,000,000 devices per km2 [11]. NB-IoT devices are expected in large numbers in homes, cars, cities and municipalities [13], [14]. NB-IoT Network Planning Capacity Analysis for Smart Metering

Services refers to 3GPP Rel.13 TR 45 820. To assess NB-IoT system capacity, two cities, London and Tokyo, are used as models to determine population, household density, and number of NB-IoT devices in use. This target is based on the use of 40 devices per household. Table 2 shows the number of devices per cell site area resulting from multiplying the area of the cell site area by the density of households in a square area, and the number of devices per household so that the capacity of these services can at least support up to 52,547 devices in the cell site area.

Table 2: CIoT capacity for London and Tokyo urban areas

City	Household Density per km^2	ISD (m)	Area of Cell Site Sector (km^2)	Number of devices per household	Number of devices within a Cell Site Sector
London	1517	1732	0.866	40	52548
Tokyo	2316	1732	0.866	40	80226

The number of devices per site sector is given by the following formula:

$$N_{ap/sec} = S_0 * \rho * \sigma \qquad \text{Eq. 20}$$

Where S_0 is the cellular site sector, ρ is the density of household per km2 and σ is the number of devices per household.

In urban area, all sites have 3 sectors, then the number of devices in a sites is equal to the number of site sector times 3.

$$N_{ap/site} = 3 * N_{ap/sec} \qquad \text{Eq. 21}$$

Le nombre total d'appareils dans la zone cible est donné par :

$$Nap = N_{hh} * N_{dev\ per\ hh} \qquad \text{Eq.22}$$

N_{hh} : Number of households

$N_{dev\ per\ hh}$: number of devices per household

N_{eNB}: number of eNodeB is calculated as follows:

$$N_{eNB} = \frac{\mathrm{Nap}}{Nap/site} \qquad \text{Eq. 23}$$

Based on this model, the total number of devices projected for electricity, water and gas smart metering services in the city of Douala is 9966510 and in the city of Yaoundé 9766953.

Table 3: Capacity planning for the city Douala.

City	Household Density per km^2	Area of Cell Site Sector (km^2)	Number of devices per household	Number of devices within a Cell Site Sector
Douala	15820	3.59	3	**170381**
	Total number of devices		Number of eNodeB	
	9966510		**19**	

Table 4: Capacity planning for the city of Yaoundé.

City	Densité des ménages par km^2	Area of Cell Site Sector (km^2)	Number of devices per household	Number of devices within a Cell Site Sector
Yaoundé	17790	3.59	3	**191598**
	Total number of devices		Number of eNodeB	
	9766953		**17**	

It follows from the calculation that the city of Douala requires 19 sites and that of Yaoundé 17 sites to carry Nb-IoT traffic (see Tables 3 and 4).

3.4.2 Second procedure

In this part, we are modeling services and connected devices. Modeling end devices, sensors, and other connected objects yields the IoT service model. This service model is presented as follows:

- Fleet management: the end device can send a packet in the network every 30 seconds to track a vehicle;
- Logistics: a terminal device can send a packet in the network every 5 minutes to signal its busy state;
- Water meter: can send a packet once a day to inform about water consumption;
- Electricity meter: can send a packet once a day to inform about electricity consumption.

In this second procedure, parameters such as the frequency of transmission of packets at peak time, the number of devices connected for each type of service, the number of packets per day for a device, the break margin, the safety margin are taken into account to scale the capacity. It consists of determining the number of packets for each service and the total number of packets per day for all services. Traffic characteristics and technical requirements are the basis used to determine the capacity needed for planning IoT networks for smart meter services. To anticipate the peak hour load, a margin is required as a solution. The solution consists of two margins, a burstiness margin and a safety margin. Burst margin provides the highest percentage of network overload assumptions to minimize traffic spikes. The function of the headroom is to manage burst traffic on a small time scale. As for the traffic calculation for NB-IoT services, the percentage value of the Burstiness margin and the safety margin assumptions were 20% and 10%. The total number of data packets needed in one day for the cities of Yaoundé and Douala can be seen in Tables 5 and 6 below.

This model describes the different services provided by the network by identifying the characteristic parameters of the different types of services. The capacity of a site is 1800000 packets. The following formulas are used.

$$Np(i) = 24 * F(i) * N * n(1 + Mb)(1 + Ms) \qquad \text{Eq. 24}$$

$$Np(i) = 31.68 * F(i) * N * n \qquad \text{Eq.25}$$

Pour Ms = 10% et Mb = 20%

Np: number of packets per day for service i

F: packet transmission frequency at busy hour for service i

N: number of end devices

n: number of packets per day for a device

Mb: packet break margin

Ms: safety margin

Tpacd: Total number of packets per day

The Total number of data packets needed in a day is given by:

$$Tpacd = \sum_{i=1}^{k} Np\,(i) \qquad \text{Eq. 26}$$

The number of eNodeB can be calculated as follow:

$$\boldsymbol{number\ of\ eNodeB} = \frac{\boldsymbol{Tpacd}}{\boldsymbol{single\ site\ capacity}} \qquad \text{Eq. 27}$$

Table 5: Capacity dimensioning of Yaoundé city, Source [11].

NB-IoT services	Packet transmission frequency at BH(F)	End device number(N)	Number of packets per day for one device(n)	Burstiness Margin(Mb)	Security Margin(Ms)	Number of packets(Np)
Sensor	1	5000	24	20%	10%	3801600
Metering water	0,04	600000	1	20%	10%	760320
Metering electric	0,04	600000	1	20%	10%	760320
Public lightning	2	10000	1	20%	10%	13200
Parking management	2	4000	48	20%	10%	12165120
Tracking logistic	2	1000	48	20%	10%	3041280
Asset Tracking	3	1000	72	20%	10%	6842880
Agriculture	1	1800	24	20%	10%	1368576
Wearables	0,5	6000	12	20%	10%	1140480
Home automation	0,5	2500	12	20%	10%	475200
Total number of packets per day						**30368976**

$$\boldsymbol{number\ of\ eNodeB} = \frac{\mathbf{30368976}}{\mathbf{1800000}} = \mathbf{17}\ ,$$

17 eNodeB are needed to provide service in Yaoundé.

Table 6: Capacity dimensioning of Douala city, Source [11].

NB-IoT services	Packet transmission frequency at BH(F)	End device number(N)	Number of packets per day for one device(n)	Burstiness Margin(Mb)	Security Margin(Ms)	Number of packets(Np)
Sensor	1	5000	24	20%	10%	3801600
Metering water	0,04	500000	1	20%	10%	633600
Metering electric	0,04	500000	1	20%	10%	633600
Public lightning	2	10000	1	20%	10%	13200
Parking management	2	4000	48	20%	10%	12165120
Tracking logistic	2	1000	48	20%	10%	3041280
Asset Tracking	3	1100	72	20%	10%	7527168
Agriculture	1	1800	24	20%	10%	1368576
Wearables	0,5	6000	12	20%	10%	1140480
Home automation	0,5	2500	12	20%	10%	475200
Total number of packets per day						**30799824**

$\boldsymbol{number\ of\ eNodeB} = \frac{\mathbf{30799824}}{\mathbf{1800000}} = \mathbf{18}$, 18 eNodeB are needed to provide service in Douala.

3.5 Design of an android App for NB-IoT planning

In this part we present the design of an android App developed with the following functionality for smart metering solution:

- Perform a link balance to determine the maximum allowable losses on that link Calculate the coverage radius of a cell;
- Calculate the number of base stations required to provide full coverage of the area;
- Calculate the maximum number of packets per sector;
- Calculate the total number of packets in a cell;
- Determine the number of base stations required to support the capacity of the target area;
- Present the curves and the amount of consumption per utility (electricity, water or gas);
- Access to real-time data;
- Checking and control of monthly consumption.

Design is an important phase in the development cycle of a project. The support of this phase is done by appropriate techniques and tools to produce a high quality software and applications. The design should take into account the needs, experience and capabilities of the user. In our approach, we will use the industrial standard of object modeling UML, to have a good understanding of the functioning of the tool to be produced. For this purpose, we will produce diagrams such as: class diagrams, system sequence diagrams and use case diagrams.

3.5.1 Use case diagram

The set of use cases describes the objectives of the system. It constitutes the use case diagram whose graphical representation is as follows:

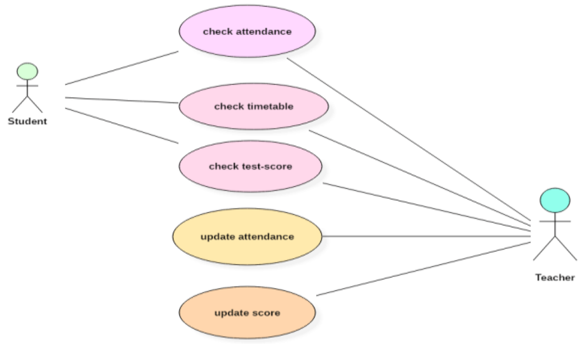


Figure 7: Example of Use Case Diagram.

They are represented by the use cases, the system (with its boundary), the actors (primary and secondary) and the associations between actors and use cases. The actors and use cases of a system are linked by an association relationship which materializes the communication between an actor and a use case and is represented by a continuous line (see representation above).

To this end, we can, in view of the previously defined actors, highlight the following use case diagrams for our application:

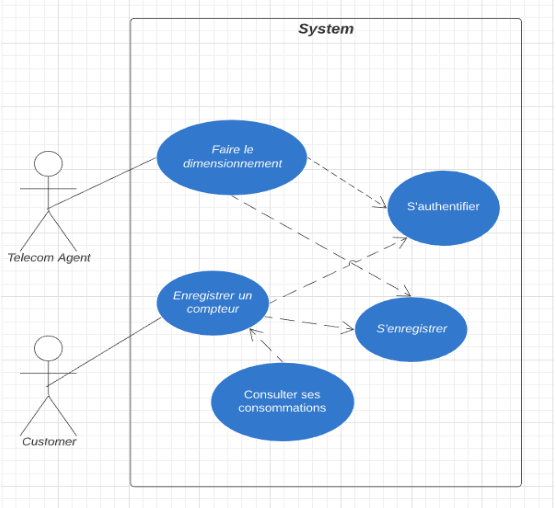


Figure 8: NB-IoT application use case diagram.

3.5.2 Class diagram

It is presented by the following figure.

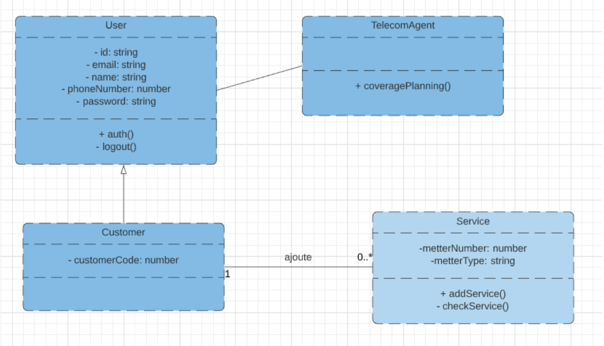


Figure 9: Class diagram for proposed NB-IoT App.

3.5.3 Activity Diagram

Some activity diagrams are presented below for our proposed system:

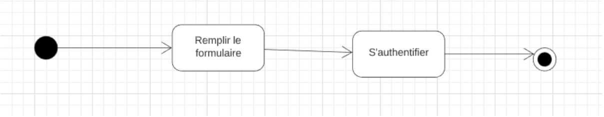


Figure 10: Sequence diagram of the case « Authentication »

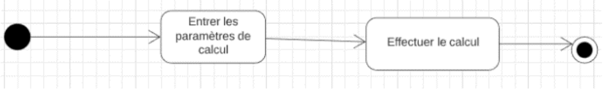


Figure 11:Sequence diagram of the case « Enter »

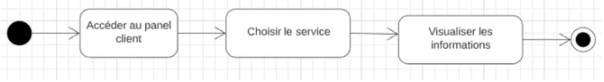


Figure 12: Sequence diagram for the case « inscription »

This part was devoted to the modeling of the App to be developed. All this work led to results which will be presented in the next chapter, the result of coverage and capacity planning were already include inside the related part because of the pedagogic approach which obliged us the develop the idea till the end by presenting the related results for the specific case of the selected towns.

4. RESULT AND COMMENT

The methodology used to solve the problem posed above has allowed us to obtain the results that will be presented in this chapter. To do this, we will proceed to a presentation of the different interfaces constituting the developed software, accompanied by some related comments.

4.1 The authentication page

When you access the application, you are directed to this screen. It contains the application registration and login form. The user must fill in the fields to have access to the modules allowing him to carry out the task he wants to accomplish. After filling in these fields, to authenticate, he clicks on the connect button. Figure 13 presents the authentication page. After a successful login, we have the interface presents in figure 14.

Figure 13: Authentication page

4.2 Moduls interface

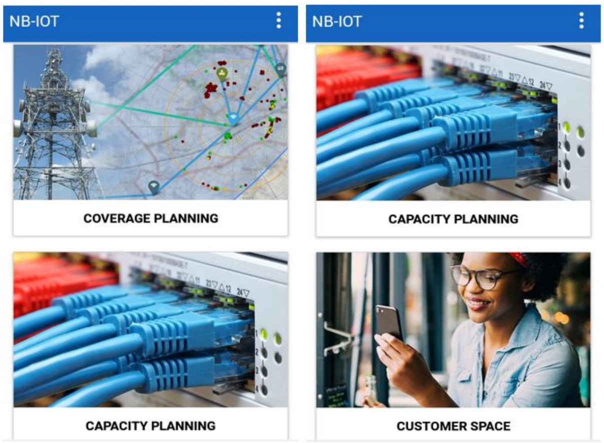


Figure 14: Moduls interface.

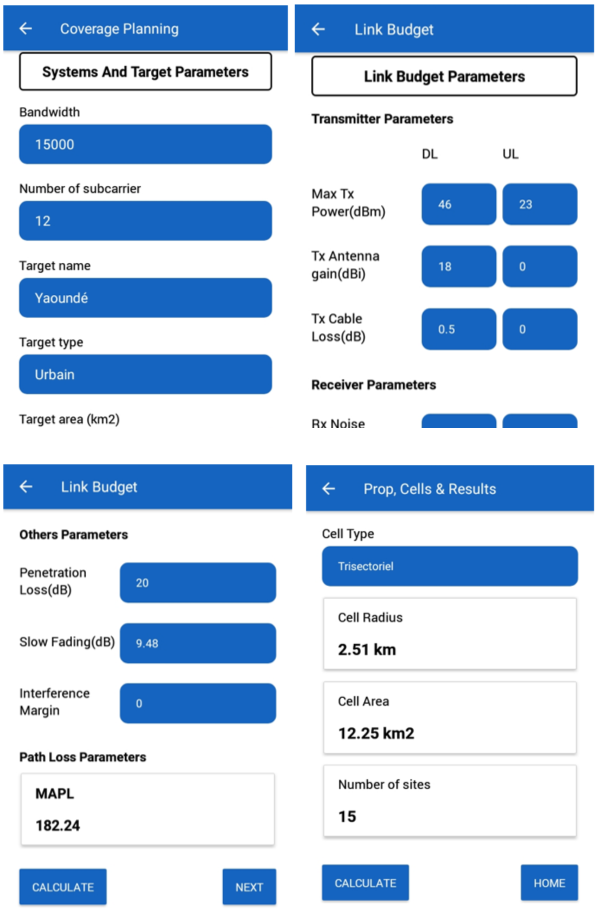
Once registered on the platform, users have access to the main screen. This interface presents the available modules, namely coverage sizing, capacity sizing and a captive data access portal.

4.3 Coverage planning interface

This interface allows to plan the coverage of the NB-IoT network for a given city. It has a multi steps form where the user enters the information and performs the calculation. This process is broken down into different tasks, including: Link budget, MAPL, coverage radius of a cell or eNodeB site, number of eNodeBs needed to cover the chosen area. This interface is a prompt to enter the various parameters of the link budget. These parameters, which are those of the UE and of the base station, are of two types: the transmission parameters and the reception parameters. Therefore, the user will have to fill in this information. The different fields to be filled in concern respectively:

- ❖ The total powers of the base station and of the UE;
- ❖ The gains of the base station and UE antennas;
- ❖ Cable losses at BS and UE respectively;
- ❖ The SINR of the base station and of the UE;
- ❖ UE and base station noise figures;
- ❖ Receiver sensitivity in DL and Ul;
- ❖ The frequency, the heights of eNodeB and UE, etc.

The following figure presents an interface for coverage planning.



Systems And Target Parameters

Bandwidth
15000
Number of subcarrier
12
Target name
Yaoundé
Target type
Urbain
Target area (km2)

Link Budget Parameters

Transmitter Parameters

	DL	UL
Max Tx Power(dBm)	46	23
Tx Antenna gain(dBi)	18	0
Tx Cable Loss(dB)	0.5	0

Receiver Parameters

Rx Noise

Others Parameters

Penetration Loss(dB)	20
Slow Fading(dB)	9.48
Interference Margin	0

Path Loss Parameters

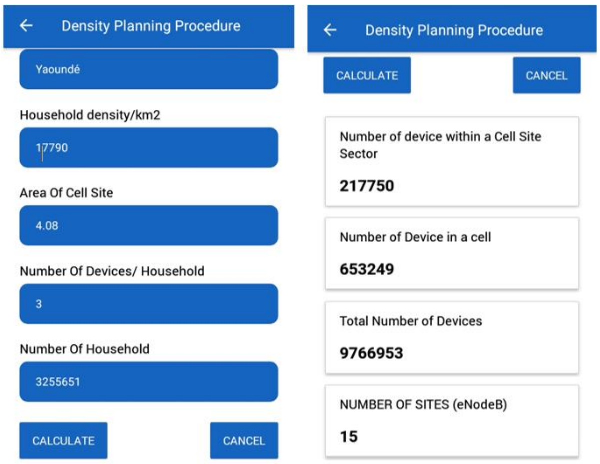
MAPL
182.24

Cell Type
Trisectoriel
Cell Radius
2.51 km
Cell Area
12.25 km2
Number of sites
15

Figure 15:Interface for coverage planning case.

4.4 Interface capacity planning

4.4.1 Based on first procedure



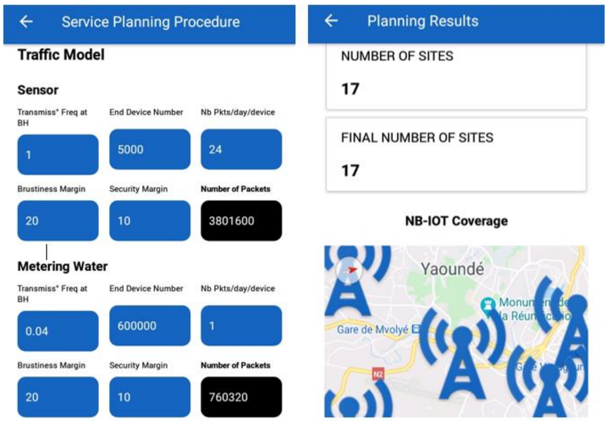
Yaoundé
Household density/km2
17790
Area Of Cell Site
4.08
Number Of Devices/ Household
3
Number Of Household
3255651

Number of device within a Cell Site Sector
217750
Number of Device in a cell
653249
Total Number of Devices
9766953
NUMBER OF SITES (eNodeB)
15

Figure 16:Interface for capacity planning based on first procedure.

This interface is used to do the capacity planning of the NB-IoT network for a given city. It has a multi-step form where the user enters the information and performs the calculation. This gives the result for the calculation of: the number of devices in a cell site sector; number of devices in a cell; total number of devices in the chosen area; total number of eNodeBs needed to handle all traffic. The "CALCULATE" button provides the number of devices in a sector, the number of devices in the cell and the number of base stations.

5.4.2 Based on second procedure



Traffic Model

Sensor

Transmiss° Freq at BH	End Device Number	Nb Pkts/day/device
1	5000	24
Brustiness Margin	**Security Margin**	**Number of Packets**
20	10	3801600

Metering Water

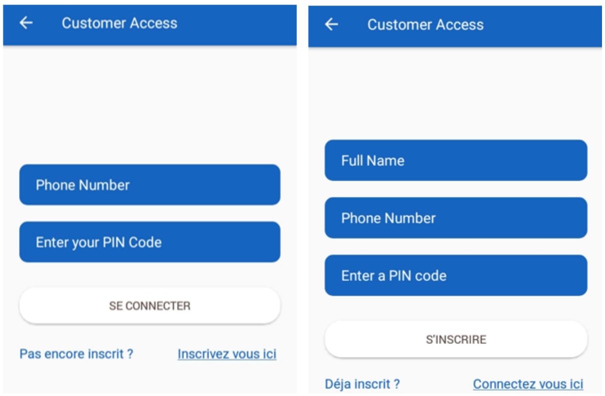
Transmiss° Freq at BH	End Device Number	Nb Pkts/day/device
0.04	600000	1
Brustiness Margin	**Security Margin**	**Number of Packets**
20	10	760320

NUMBER OF SITES
17
FINAL NUMBER OF SITES
17

Figure 17:Interface for capacity planning.

Through this interface, a capacity planning can be done based on the second method. Once clicked on the "CACULATE" button, we obtain the number of packages, the total number of packages per day.

4.5 Customer service access interface



Phone Number
Enter your PIN Code

Full Name
Phone Number
Enter a PIN code

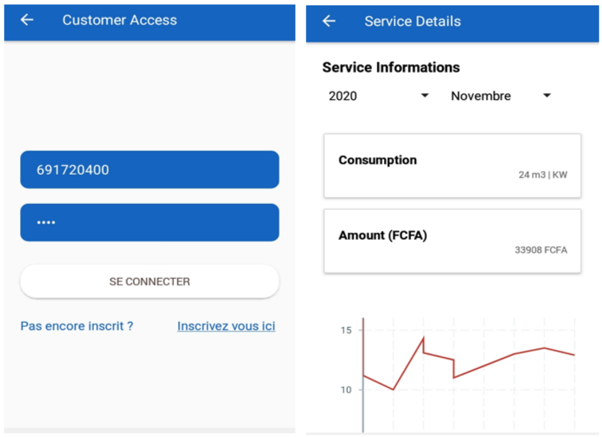
Figure 18: Customer service access interface.

This interface allows households to access their panel in order to consult their consumption. This will allow them to properly control their monthly consumption. The user must first register by entering his name, his telephone number and his code, PIN code. Then, to access the data, the user must enter their phone number and the PIN code. After these actions, the user can log in and view the consumption curves.

4.6 Customer data interface

On this interface, households can consult their consumption on the services they have registered on the platform. The customer can see the indexes of his electricity and water meter. He can also visualize the consumption curve to better take control of his consumption as shown in figure 33. This is the consumption curve according to the months. It presents the months on the abscissa, therefore from January to

December, and on the ordinate, the indexes sent by the smart meter in m3 or KWh.



Consumption: 24 m3 | KW

Amount (FCFA): 33908 FCFA

Figure 19: Users data interface.

4.7 Services interface (Water or electricity)

Figure 20:Interface for adding services

On this interface, households can add new services. This involves, for example, registering a new electricity meter to be able to monitor consumption. To this end, the customer enters the number of his NB-IoT smart meter and his personal information such as name, telephone number, etc. Once informed, he can consult his consumption curve.

The results of the calculations show that the number of sites required is different both in terms of coverage and capacity, and the highest number of sites has been taken to meet the requirements. Thus, the number of sites required is 19 for the city of Douala and 17 for the city of Yaoundé. The initial results obtained in this work are acceptable and encouraging.

5. CONCLUSION

At the end of our work, which focused on NB-IoT: Smart Metering in the cities of Yaoundé and Douala, it is important to take stock of the different articulations addressed. Firstly, our objective was to develop a planning solution that could enable an operator using 1800MHz band to deploy the future NB-IoT network, whose operation will be subordinate to the existing 4G network infrastructure, in order to create a new source of revenue in the digital era. Subsequently, we presented the coverage and capacity planning of the NB-IoT network. Referring to previous works, including articles, theses and publications, on similar topics, we adopted a methodology that allowed us to clearly identify the expected solution. The number of sites required is 19 for the city of Douala and 17 for the city of Yaoundé. We have also propose and App which can embedded all this solution.

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