

Radio access model for universal service

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Abstract— This paper proposes a mathematical model as a decision tool for the choice of radio access solutions adapted to a geographical region through universal access. It integrates the formalism related to engineering radio network access in general as well as financial constraints imposed by the access and universal service funds. Services considered are voice and data services. This approach has helped to derive a general expression set for radio technologies. The coverage and capacity deployment strategy has also been combined to clarify the optimal implementation based on financial constraints. A case study on the Ouaddai region in Chad accompanied by simulations curves for wireless technologies as Wi-Fi, WiMAX and CDMA for example has shown the efficiency of such approach.

Keywords— universal access, radio access, universal service, radio access model, access network model.

I. INTRODUCTION

Information and Communication Technologies (ICT) are crucial for the socio-economic development of peoples and contribute to the emergence of countries.

However, according to geographical membership and/or socio-economic category, the access to ICT is achieved in a non-egalitarian and disparate manner between peoples. This technological gap is explained by the fact that neither the needs for services, nor the purchasing power are the same. This leads governments to define an investment policy fostering rural areas in order to fill the gap with dense and profitable areas. In order to raise tele-density and reduce the disparities of access, the authorities and regulatory agencies have introduced the concept of universal access and services by dedicating a fund called Universal Service Fund (FSU).

Considering the convergence and neutrality of technologies, communications infrastructures and the associated services now have a central role in economic organization [1-5]. In fact, access to these infrastructures and services depend on the ability of countries and citizens to participate in the flow of communications. For that reason they must put in place policies which will help to avoid the exclusion of some categories of users or geographic areas deemed to be of non-profitable nature by the operators.

In this context access and universal service could be considered as a major problem. This is to ensure that quality

and price for consumer satisfaction as well as profitability from the point of view of operators might be taken into account. In order to respond to this problem, the solution should come from pairing technical/economic approaches and taking into account geographical constraints inherent to each country.

Gasmi & Recuero Virto [4] have reviewed the provision policies of telecommunications services in rural areas for developing countries. They have shown that these policies differ from those usually applied in advanced countries in their basic objectives, technological strategies deployment, the role of the market and institutional environments. Falch & Henten [6] have studied the appropriate policy measures to put in place in Europe to achieve universal access. They have shown that it is interesting to implement a combination of different technologies and strategies. Xavier [7] provides an overview of the principal issues related to universal access and the provision of universal service.

In this paper, an access radio technology model for universal service is proposed. We have established a model of access network design common to radio technologies which has been adapted to universal service funds limitations. The number of base stations based on the project duration for each radio technology has been derived. This has made it possible to decide the optimal strategy deployment coupling the radio coverage for data and voice services. The efficiency of this approach is shown thanks to the case study applied to Ouaddai region in Chad.

In the rest of this article Section 2 presents the modelling approach for determining the different elements of the access network and profitability model. Section 3 offers a case study that will highlight on the usefulness of the approach. Finally, Section 4 concludes this communication.

II. THE MODELLING APPROACH

The optimal network modelling approach proposed consists in determining the optimal network architecture for the universal access and service in an area. The methodological approach to obtain this model is based on the access network model and that of the transmission network. The determination of the access network model of an area is carried out based on the telecommunications engineering parameters, notably those related to the demographic and financial aspects. Thus, through

this area data, the population addressable to the universal access and the bandwidth and the necessary number of base stations are determined, then the investment and operation costs (CAPEX and OPEX) are assessed in addition the energy related expenses and liabilities are defined.

The population addressable to the universal service is given by the expression:

$$P_A = (P - P_S) \times T_N \quad (1)$$

where P is the population of the target area, P_S the population having access to the universal service and T_N the service penetration rate.

The bandwidth brought back to the addressable population is determined based on the data rate/subscriber need, the data rate by user supplied by an access technology and the contention rate. It is expressed by the following relationship:

$$BP_A = P_S \times D_A \times T \quad (2)$$

where D_A represents the data rate per subscriber, P_S the population having access to the universal service and T the contention rate.

It is worth noting that the data rate/subscriber simultaneously takes the voice and data into consideration and that the contention rate has to be taken so that, even in the most unfavorable case, the voice minimum output is kept for the user, which is translated by constraint expressing that the access technology has to easily bear the cost of the subscribers data rate needs. The determination of the necessary number of base stations of the access area allies a coverage approach with a capacity approach in order to avoid the network oversizing and under-sizing problems. Thus, this number is given by the following relationship:

$$BS_{NX} = m \times BS_C + n \times BS_B \quad (3)$$

$$\text{where } BS_C = \frac{S_C}{S_{BSC}} \text{ and } BS_B = \frac{BP_A}{CapBS_X \times T_u}$$

with S_C the surface to cover and S_{BSC} the surface covered by a base station, $CapBS_X$ the bandwidth base station capacity brought back to a technology X and T_u this station use rate, m and n are the coefficients related to the coverage and capacity needs. From equation (3), the BS_X is expressed in function of m by the following expression:

$$BS_{NX} = (m \times BS_C + (1 - m) \times BS_B) \quad (4)$$

The total cost of the investment expenses (CAPEX) of a technology X is given by the expression:

$$C_C = BS_N \times capex(BS_X) \quad (5)$$

Where $capex(BS_X)$ is the investment unit cost of a given technology X .

As for the total cost of the operation expenses (OPEX) of a technology X , taking into consideration its reducing percentage r , it is determined by the expression:

$$C_O = BS_N \times opex(BS_{XN}) \quad (6)$$

with $opex(BS_{XN}) = opex(BS_{X(N-1)}) \times (1 - r)$, and where $opex(BS_{XN})$ is the operation unit cost of a base station at year N brought back to technology X .

As a matter of fact the operation decreases each year with a positive constant reducing percentage r . This decrease is due to the fact that a piece of equipment is used, some mastery is acquired which reduces the operation cost as the years go.

The access total cost of a technology X is the sum of total CAPEX, OPEX total operation over the whole duration of the

project and allied expenses. The allied expenses include the investment and operation expenses of the liability infrastructures as well as those of energy workshops. Taking into account, on the one hand, that the OPEX cost represents 5% of the CAPEX costs [8] and, on the other hand, that the energy OPEX cost represents 25% of the CAPEX in energy [8], the investment and operation costs of the liability infrastructures as well as those of the energy workshops, while simultaneously integrating the OPEX and CAPEX costs, are determined by the following expressions:

$$CTI_X = 1.05 \times BS_N \times c_i \quad (7)$$

$$CTE_X = (1.25 \times c_e) \times \sum_{k=0}^T BS_{NXk} \quad (8)$$

with c_i the liability infrastructure unit cost and c_e the energy unit cost.

Thus the allied expenses CC are given by the expression:

$$CC = CTI_X + CTE_X \quad (9)$$

whereas the access total cost is given by the following relationship:

$$CTA_X = CC + C_C + \sum_{k=0}^T C_{OXk} \quad (10)$$

Expressing the OPEX summation of the access technology and using equation (5), it is possible to write:

$$\begin{aligned} \sum_{k=0}^T C_{OXk} &= BS_0 \times opex(BS_{X0}) + BS_1 \times opex(BS_{X1}) + \dots \\ &\quad + BS_T \times opex(BS_{XT}) \end{aligned} \quad (11)$$

where $opex(BS_{X1}) + \dots + BS_T \times opex(BS_{XT})$ and $opex(BS_{X2}) = opex(BS_{X1}) \times (1 - r)$

The following expression is obtained:

$$\begin{aligned} \sum_{k=0}^T C_{OXk} &= opex(BS_{X0}) \\ &\quad \times [BS_0 + BS_1 \times (1 - r)^1 + \dots + BS_T \\ &\quad \times (1 - r)^T] \end{aligned} \quad (12)$$

Thus, the total cost of the access network is determined by the following global expression:

$$\begin{aligned} CTA_X &= CC + C_C + opex(BS_{X0}) \\ &\quad \times [BS_0 + BS_1 \times (1 - r)^1 + \dots + BS_T \\ &\quad \times (1 - r)^T] \end{aligned} \quad (13)$$

In practice, a region or an area is the object of a commercial launching when the total set of stations are deployed. This simplifies the expression (13) which becomes:

$$\begin{aligned} CTA_X &= BS_X \times \{1.05 \times c_i + (1.25 \times c_e) \times \\ &\quad (T + 1) + capex(BS_X) + opex(BS_{X0}) \times \\ &\quad [1 + (1 - r)^1 + \dots + (1 - r)^T]\} \end{aligned} \quad (14)$$

$$\begin{aligned} CTA_X &= BS_X \times \{1.05 \times c_i + (1.25 \times c_e) \times \\ &\quad (T + 1) + capex(BS_X) + opex(BS_{X0}) \times \\ &\quad [1 + (1 - r)^T]/[-r]\} \end{aligned} \quad (15)$$

For a given technology, it is possible to establish a connection between the $opex(BS_{X0})$ and the $capex(BS_X)$. Suppose in this case that this connection is α , then expression (16) becomes:

$$CTA_X = BS_X \times \{1.05 \times c_i + (1.25 \times c_e) \times (T + 1) + capex(BS_X) \times [-r + \alpha + \alpha \times (1 - r)^T] / (-r)\} \quad (16)$$

Then, we can finally get BS_X expression as follows:

$$BS_X = \frac{CTA_X}{\{1.05 \times c_i + (1.25 \times c_e) \times (T + 1) + \alpha - \alpha \times \frac{[1 + (1 - r)^T]}{[-r]}\}} \quad (17)$$

In a given locality, the access technology X to choose will be the one that will have the lowest access total cost CTA_X among all the technologies submitted to this algorithm.

This profitability makes it possible to evaluate the total amount of the subsidy necessary to achieve the project but also the adequate purchasing power (ARPU) needed to ensure the population accessibility to the service. The analysis of the model shows that the whole set of the expenses from which the subsidy on the project duration is subtracted has to be lower than what the operator will earn over the same duration (number of subscribers over the project study duration multiplied by the ARPU).

III. CASE STUDY

In order to apply and assess the proposed approach, as an illustration, the Ouaddaï (Chad) region is considered. It has an area of 36,685 km² including a population of 1 367 166 inhabitants. This area includes three localities with identical needs in data rate/inhabitant but the needs in bandwidth differ from a locality to another. Tables 1 and 2 below sum up the set of collected data.

TABLE 1. OUADDAÏ AREA BASIC DATA (SOURCE ARCEP CHAD)

Data	Locality 1	Locality 2	Locality 3
Area	11 611	15 229	9 845
Population	852 389	388 448	126 329
Penetration rate	43.66	43.85	44.40
Need in output/subscriber (Kbps)	256	256	256
Population Ps	371547	170755	56078
Addressed Population (PA)	209647	95350	31121
Appropriate bandwidth (Bp_A) by Mbt/s	53 669 660.67	24 409 480.70	79 67 025.41

Table 1 represents the actual data of the Ouaddaï region (Chad) with locality1 situated in city centre, locality2 situated in periphery and locality3 situated in rural zone. This distribution corresponds to the administrative division: the zone corresponds to the region, the locality corresponds to the three departments which are distributed into communities. This table makes out for each considered locality:

- the population data (geographical area, number of inhabitants);

- the subscribers park of the set of electronic communications services;
- ICT penetration rate;
- needs in output/subscriber and necessary bandwidth (BP_A).

The analysis of table 1 reveals that according to IUT's definition of universal access, it is important to have an output of 256Kbps to supply the necessary services. For the set of considered localities, a penetration rate inferior to 45% is recorded. The penetration of services related to the data is low, which justifies the significant need in bandwidth of the localities.

Table 2 below gives the outputs supplied by the different technologies, the surfaces covered by a base station (BS) of technology X as well as the maximum capacity of BS's. It also shows the CAPEX, OPEX of the base stations by technology and the cost of liability infrastructures as well as those energy-related.

TABLE 2. DATA RELATED TO TECHNOLOGIES

Data	WIFI	WIMAX	CDMA
Data rate (D_X)	54	70	3.1
Surface covered by BS (S_{BSC})	0.13	200.96	5024
BS capacity ($CapBS_X$)	100	30	64
CAPEX (BS_X) in Euro	13.71	1494	68 597.561
OPEX (BS_X) in Euro	2.06	224.08	10 289.63
CTA (Euro)	1524390.24	1524390.24	1524390.24
C_i	1	2 003	10 015
C_e	7 621.95	25 914,63	85 129.57

- After analysing tables 1 and 2, the number of base stations by technology is determined following equation (17) and according to the following conditions:
- variation of duration T of the project as well as that of the OPEX coefficient reduction r ;
- only at the variation of the reducing coefficient r ;
- variation of coefficient m linked to the coverage in accordance with equation (4).

Figure 1 below represents the number of stations by technology according to the variation of the reducing coefficient and the project duration. This graph makes it possible to see the evolution of the BS_X of the zone, for the same r and T the number of BS_X differs according to technology X. It is worth noting that if the project duration T increases, the number of BS_X decreases.

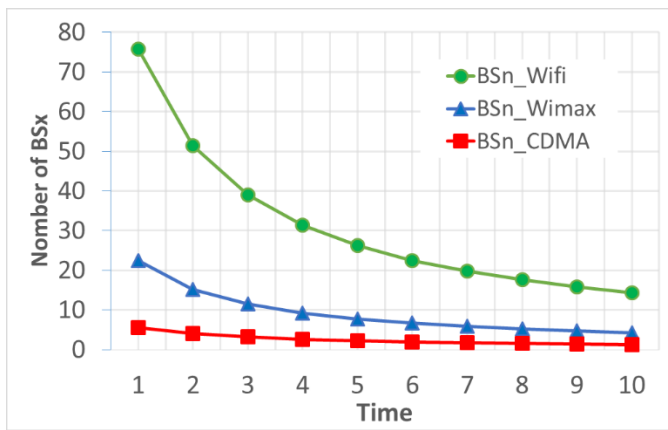


Figure 1. Evolution of the number of base stations by technology according to a variation of duration T and reducing coefficient

Figure 2 shows the evolution of the base stations of three access technologies (Wi-Fi, WiMAX and CDMA in accordance with the variation of reducing coefficient r . Based on the depreciation of the telecommunications equipment, the project duration T is 5 years. It established that if the duration T is constant, the variation of the reducing coefficient r has no effect on the number of BS_x . The BS_x by technology practically remains constant even if r varies.

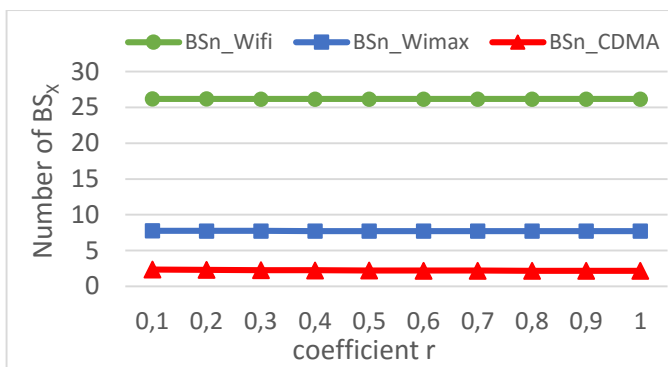


Figure 2. Evolution of the number of base stations by technology in accordance with coefficient r .

Figure 3 shows the evolution of the number of base stations of three technologies following the deployment approach directed to coverage and capacity coverage objectives. When m varies, it is noted that for a technology X, the needed number of stations varies significantly. It is worth indicating that for the two extreme values (0 and 1) of m , the base station number decreases very significantly following technology X. This shows that it is easier to reach the coverage goals than those related to the quality of service and capacity. Thus, it is noted that the CDMA technology allows the coverage objectives to be reached more easily, the Wi-Fi and WiMAX, on the other hand, are more efficient for capacity oriented deployment.

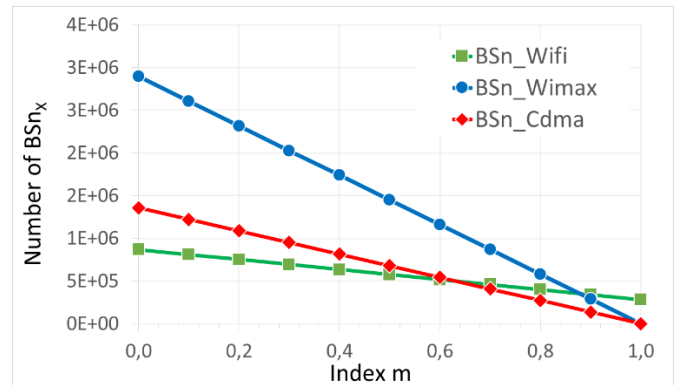


Figure 3. Evolution of the number of base stations by technology according to the m variation

IV. CONCLUSION

The aim of this paper was to suggest an optimal model to define the network architecture based on radio technologies for universal access and serves. This approach makes it possible on the basis of the universal service access fund allocated to each locality to determine the communication needs in terms of output, bandwidth and the amount of equipment needed by technology.

The application of this approach to the Ouaddaï area located in Chad allows the gradual deployment policy, distributed over a duration, of the cheapest cost coefficient network.

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