Income-oriented Broadband Access Planning with xDSL and APON-FTTC

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***Abstract**: The appearance of new technologies, services and players is imposing significant changes to the traditional telecommunications system. Given the magnitude of costs and other involved financial values, careful studies of multi-service, market-like scenarios are required. Besides, competition among technologies must be taken into account. Under these assumptions, this work presents a model for supporting decisions related to the access network. It is assumed that two technologies are the major competitors: the copper-based xDSL and the optical-based APON-FTTC. The search of optimal plans is made under an income-maximisation criterion, but constraints on budget are also stated. An application based on actual data is reported and allows both to verify the behaviour of the model and to discuss several settings of equipment costs and services' penetration levels.*

1. INTRODUCTION

Operator companies are under pressure in the current telecommunications scenarios. The competitive environment imposes a focus changing, from minimum-cost investment [1][2] to the search of network solutions that guarantee both participation in the market and a worthy income.

This brings new concerns for the planning stage. Demands for services that are more profitable deserve greater attention. New services are always rising. Each of them has its own penetration level and income profile, and sometimes may require specific equipment, topologies and transmission media. The budget constraint, naturally, is another factor to be taken into account, since to deploy all necessary systems for the total meeting of the demand is not always possible. The demand may be selectively met.

In order to deal with the diversity of services, most of the planning methodologies group them according to their main characteristics. A useful classification [3] establishes four profiles: POTS (*Plain Old Telephone Service*), ISDN (*Integrated Services Digital Networks*), ASB (*Asymmetric Switched Broadband*) and SSB (*Symmetric Switched Broadband*).

Nowadays, the main technological options to be used in the network expansion to provide the above services are xDSL (*Digital Subscriber Line*), FITL (*Fibre-in-the-Loop*), and/or LMDS (*Local Multipoint Distribution Service*), which is a kind of FWA (*Fixed Wireless Access*) approach. The network solution found by the planner can use either one or more technologies. The plan to be adopted will depend on the operator's objectives, as well on the scenario in study itself.

Therefore, equipment manufacturers and service providers need to be prepared for new challenges, both from the technological and from the marketing point-of-view. Given the complexity and the range of this task, it is convenient to use decision-support tools that are based on mathematical models.

In this work, a mathematical model is proposed for helping the broadband, multi-service access network planning. The model incorporates the competition between two technologies: xDSL and APON-FTTC (*ATM-based Passive Optical Network - Fibre-to-the-Curb*). The objective is to obtain the maximal income from the services, while considering foreseen demands, network topologies, equipment capacities and costs of the candidate technologies. Existent facilities, as the copper-based network, are also included as participants of the decision process. Modelling details for the technologies are provided.

The article is organised as follows: section 2 presents the income-maximisation model. Section 3 reports an application to an actual network. Finally, section 4 concludes the work.

2. THE MODEL FOR INCOME MAXIMISATION

2.1. Equipment for Network Expansion

Networks using xDSL and APON-FTTC equipment may be represented as in Figs. 1 and 2. We can see that POTS does not utilise any special equipment and ISDN requires a Network Terminal (NT). Broadband services, however, need specific modems to be installed at users' premises.

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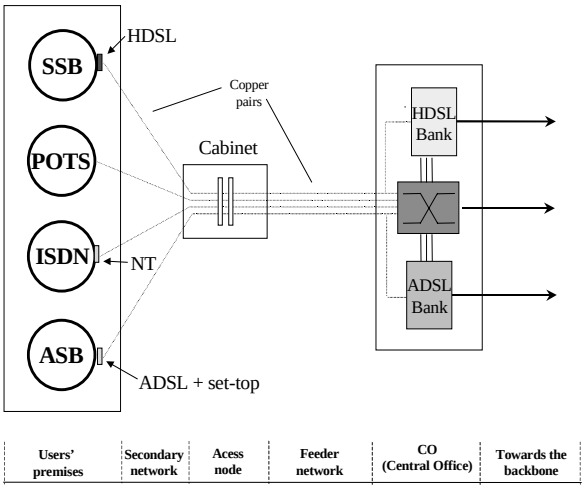

Fig. 1. xDSL solution for the access network.

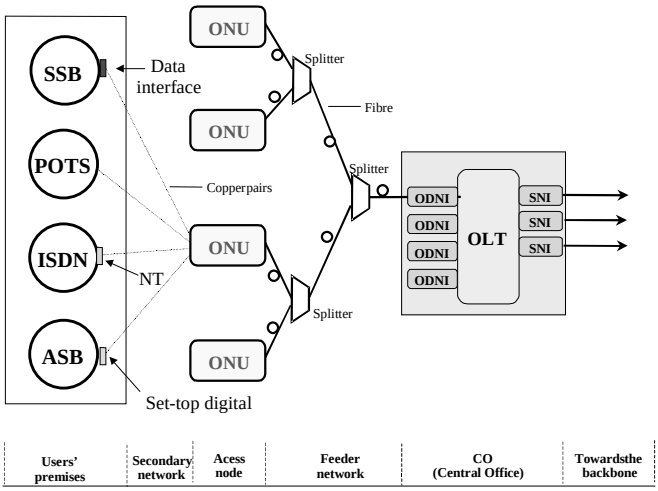

Fig. 2. APON-FTTC solution for the access network.

For xDSL expansion, only copper cables and modems are deployed. Only one cabinet is assumed per access node. For APON-FTTC expansion, the access node is extended nearer to users. *Optical Network Units* (ONUs) are responsible for the electric-optical conversion in the outside plant. The number of splitters to be used depends on the network and is assumed to be given by the planner. The *Optical Line Terminal* (OLT) is the main equipment to be installed in the Central Office (CO). It deals with ATM packets and SDH transfer modules. Each OLT's capacity depends on the configuration of services. Several access nodes (i.e., several ONUs) may share the same OLT. An *Optical Distribution Network Interface* (ODNI) connects an ONU to an OLT. Each ODNI is devoted to a single APON-FTTC access node. ODNI's capacity also depends on the carried services. *Service Network Interfaces* (SNIs) are needed to the link with the backbone.

2.2. Graphic Network Representation

The network's physical disposition suggests the use of graph [7]. Fig. 3 is the model of an *Access Node i*. The following elements are presented:

– *Artificial Service Nodes*: we assume that total demand for each service (*DEM01–DEMn*) is already known. Artificial nodes (*SV01–SVn*) represent the services. They are linked to all *Access Nodes* through *Flow Arcs*. It is mandatory that all the demand values at the *Artificial Service Nodes* have the same measure unit, number of subscribers for instance.

– *Access Node*: it works as a concentration point, putting together the demand that arrives from the *Artificial Service Nodes*. Each *Access Node i* is partitioned in two: the first part represents the access via the *Copper Network* (CpN_i), while the second part represents the access via the *Candidate APON-FTTC Solution* (ApF_i). Thus, it is possible to take into account the existent copper network, as well as to model its expansion.

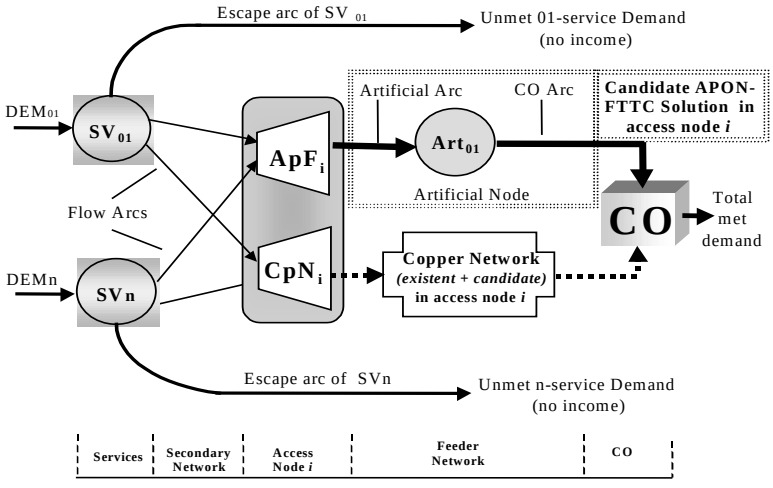

Fig. 3. Graph representation of max-income problem.

– *Flow Arcs*: they link all *Artificial Service Nodes* (*SV01–SVn*) to all *Access Nodes* ($CpN_i + ApF_i$). The demand flow carried by these arcs is used to compute the income from the offered services. The main objective of the optimisation model is to maximise the flow through these arcs. Their capacities can be handled in order to guarantee a minimum/maximum demand meeting level at each of the *Access Nodes*.

– *Copper Network*: this graph segment models both the *Existent* and the *Candidate* copper network. The *Existent Network* assures the recognition of the available infrastructure in the network, such as cables and ducts; the *Candidate Network* represents the necessary components for the copper network expansion.

– *Candidate APON-FTTC Solution*: represents the APON-FTTC technology to be used in the network evolution. The *Art01 Node* acts as a concentration point, putting together the demand flow that arrives from the *APON-FTTC Access Nodes.* The ODNI is modelled through an *Artificial Arc*. The OLT (shared among several *APON-FTTC Access Nodes*) is modelled by the *CO Arc*.

– *CO Node*: this graph node is physically associated to Central Office (CO). We assume that each subscriber is linked to only one CO. All the demand effectively met by the network is carried to this node.

– *Escape Arcs*: due to the budget limit, the *Total met demand* can be lower than the summation of the services' demands (*DEM01–DEMn*). Some demands for some services may not be met. In order to guarantee the flow balance, we place at each *Artificial Service Node* an *Escape Arc*. The flow through these arcs (unmet demand) is not transformed into income.

2.3. Costs and Tariffs

While thinking about income maximisation, some considerations are deserved. First, distinct tariff values are associated to the different services. The tariffs may be either based on a fixed value (monthly, for example, as a subscription) or to depend on the effective utilisation (time spending). Sometimes, a combination of both is used. Second, the income is distributed over the analysed period. In this case, comparisons with cost make more sense whenever we take the same measure unit on both income and cost, for instance the "net present value" or some kind of "cash flow" [4]. Alternatively, we may also think cost and income are two separate, conflicting objectives. As a matter of fact, the subject has several interpretations [5][6]. In this work we adopt the criterion of "income maximisation respecting a budget limit". Regardless of time considerations, we assume that equipment and cables are deployed over a single period. OA&M costs at the period may be included along with installation costs. The income is calculated over the same period.

For the xDSL expansion, cost of the equipment at the users' premises (and their complements in the CO, if any) is placed on the *Secondary Network*. The physical secondary network (cables) can be assumed either as existent (without costs) or not (its cost is calculated from average values). In the graph, *Flow Arcs* allow evaluating such expenses. Cabinet and cable costs at the *Feeder Network* are associated to the adoption of the (candidate) *Copper Network* solution.

For the APON-FTTC expansion, cost equipment at the users' premises is also computed from the *Flow Arcs*. For each *Access Node*, the *Artificial Arc* is used to compute the costs of both the ONUs and the "secondary" optical link (by using average distances). The OLT cost, as well as the ODNIs and splitters cost, is associated to the *CO Arc*. The cost of the "feeder" optical link is associated to the adoption of the *candidate APON-FTTC* solution.

2.4. Mathematical Formulation

The mathematical formulation corresponds to a mixed-integer linear programming problem. The real decision variables refer to flow values through the arcs, while the binary and integer decision variables indicate the allocation and sizing of network facilities (transmission equipment, optical and copper cables, infrastructure) to be installed in order to meet the demand.

In the model:

– *Objective Function:* we seek to maximise the income, which is calculated by adding up the income of the met services:

$$\text{Maximise } R(y) = \sum_{(s,i)\in A_{EF}\cup A_{EM}} r_{si} Y_{si} \qquad (1)$$

Where:

R(y) : total income from the services

$\mathbf{A_{EF}}$: set of *Flow Arcs* (secondary network's arcs) associated to the APON-FTTC network

$\mathbf{A_{EM}}$: set of *Flow Arcs* associated to the xDSL (copper) network

$\mathbf{Y_{si}}$: real non-negative variable representing the flow through the arc $(s,i) \in A_E$

$\mathbf{r_{si}}$: unitary income of the service *s* offered to the *Access Node i*

The maximisation is subjected to the following set of constraints:

– *Budget Constraint:* assures that equipment allocation and sizing do not exceed the budget. The first parcel refers to the costs of the APON-FTTC solution (OLT, ODNI, splitters, optical cables, ducts, etc.). The second parcel refers to the cost of the copper network expansion (xDSL modems, ISDN interface, copper cable; ducts, etc.). The third parcel refers to the cost of the secondary network (users' equipment and user interfaces at each access node).

$$\sum_{n\in N1}\varphi^{X,n}.X_n+\sum_{n\in N2}\varphi^{Z,n}.Z_n+\sum_{(i,j)\in A_A}\sum_{n\in N3_{ij}}\varphi_{ij}^{O,n}.O_{ijn}+\sum_{i\in I_F}\varphi_i^{W,i}.W_i+\sum_{(i,j)\in A_M}\sum_{p\in C_M}\varphi_{ij}^{M,p}.M_{ijp}+\sum_{(s,i)\in A_{EF}}c_{si}.Y_{si}+\sum_{(s,i)\in A_{EM}}c_{si}.Y_{si}\ \le\ L \quad (2)$$

Where:

N1 : set of candidate types of OLT to be installed in the CO (i.e., in the *CO Arc*)
X_n : integer variable associated to the amount of OLTs type *n* installed in the CO
$\varphi^{X,n}$: cost of each piece of OLT type *n*

N2 : set of candidate types of ODNI to be installed in the CO (i.e., in the *CO Arc*)
Z_n : integer variable associated to the amount of ODNIs type *n* installed in the CO
$\varphi^{Z,n}$: cost of each piece of ODNI type *n* (includes the splitters)

A_A : set of *Artificial Arcs* (arcs that can receive the APON-FTTC technology as candidate)
$N3_{ij}$: set of candidate types of ONU to be installed in the arc $(i,j) \in A_A$
O_{ijn} : integer variable associated to the amount of ONUs type *n* installed in the arc $(i,j) \in A_A$
$\varphi_{ij}^{O,n}$: cost of each piece of ONU type *n*, whenever deployed in the arc $(i,j) \in A_A$ (includes fibre average cost)

I_F : set of APON-FTTC parts of the *Access Nodes* (nodes ApF_i)
W_i : binary variable associated to the adoption of APON-FTTC technology in the node $i \in I_F$
$\varphi^{W,i}$: cost of adopting APON-FTTC technology in the node $i \in I_F$ (infrastructure and "feeder" fibre costs)

A_M : set of arcs that can receive copper cables
C_M : set of candidate (new) copper cables
M_{ijp} : binary variable associated to the choice of copper cable, type *p*, for the arc $(i,j) \in A_M$
$\varphi_{ij}^{M,p}$: cost of copper cable, type *p*, whenever deployed in the arc $(i,j) \in A_M$

φ_{si} : cost of secondary network needed by service *s* at the *Access Node i*, while using arc $(s,i) \in A_{EF} \cup A_{EM}$
L : budget limit

– *Flow Balance Constraints:* guarantee the flow balance at the graph nodes. In (4), we assume that service SSB requires two copper pairs. Depending on the service profiles, the coefficients of the incidence matrix may be used in (5) for dealing with the diversity of the services' transmission rates.

$$\sum_{i\in(I_F\cup I_M)}Y_{si}+Yesc_s=d_s\ ,\ \forall s\in I_S \quad (3)$$

$$\sum_{j\in J1}Y_{ij}-\left[Y_{S1i}+Y_{S2i}+Y_{S3i}+2.Y_{S4i}\right]=0\ ,\quad \forall i\in I_M \quad (4)$$

$$\sum_{j\in J1}Y_{ij}-\sum_{j\in J2}Y_{ji}=0\,,\ \forall i\in I\text{-}(I_S\cup I_M) \quad (5)$$

Where:

I : set of all nodes, except the node CO
I_S : set of *Artificial Service Nodes*
I_M : set of copper parts of the *Access Nodes* (nodes CpN_i)
J_1 : set of nodes *j* directly connected to the node *i* by arcs emanating from *i* to *j*
J_2 : set of nodes *j* directly connected to the node *i* by arcs emanating from *j* to *i*
Y_{ij} : real non-negative variable representing the flow through the arc (i,j)
$Yesc_s$: real non-negative variable representing the flow through the *Escape Arc s* (unmet demand for service *s*)
d_s : total demand for service *s*, entering the network at the node $s \in I_S$

– *Technical Capacity Constraints*: assure that the demand is carried through the network according to the capacity of each link. Constraints (6) and (7) refer to ONU's capacities (in number of narrowband and broadband subscribers). Constraints (8) and (9) address ODNI's capacities (in downstream and upstream transmission rates). Constraints (10) and (11) stand for the sizing of OLTs (in number of narrowband and broadband subscribers). The constraint (12) bounds the number of ODNIs that can be managed by the OLTs. Finally, the metallic network sizing (xDSL modems, cables, etc.) is given by constraints (13).

$$\sum_{n \in N3ij} cap_{nb}^{O,n} . O_{ijn} \geq \sum_{(s,i) \in A_{EFnb}} Y_{si} \quad , \quad \forall \ (i,j) \in A_A \tag{6}$$

$$\sum_{n \in N3ij} cap_{bb}^{O,n} . O_{ijn} \geq \sum_{(s,i) \in A_{EFbb}} Y_{si} \quad , \quad \forall \ (i,j) \in A_A \tag{7}$$

$$\sum_{n \in N2} cap_{ds}^{Z,n} . Z_n \geq \sum_{(s,i) \in A_{EF}} bd_s . Y_{si} + \sum_{(s,i) \in A_{EFbb}} bd_{s_1} . Y_{si} \tag{8}$$

$$\sum_{n \in N2} cap_{us}^{Z,n} . Z_n \geq \sum_{(s,i) \in A_{EF}} bu_s . Y_{si} + \sum_{(s,i) \in A_{EFbb}} bu_{s_1} . Y_{si} \tag{9}$$

$$\sum_{n \in N1} cap_{nb}^{X,n} . X_n \geq \sum_{(s,i) \in A_{EF}} Y_{si} \tag{10}$$

$$\sum_{n \in N1} cap_{bb}^{X,n} . X_n \geq \sum_{(s,i) \in A_{EFbb}} Y_{si} \tag{11}$$

$$\sum_{n \in N1} cap_{odni}^{X,n} . X_n \geq \sum_{n \in N2} Z_n \tag{12}$$

$$\left(pi_{ij} + \sum_{p \in C_M} \left[pc_{ijp} . M_{ijp} \right] \right) \left(1 - fdc_{ij} \right) \geq Y_{ij} \quad , \quad \forall (i,j) \in A_M \tag{13}$$

Where:

$cap_{nb}^{O,n}$: capacity of ONU type *n*, expressed in terms of narrowband subscribers

$\mathbf{A_{EFnb}}$: subset of *Flow Arcs* associated to the APON-FTTC network that carry narrowband services

$cap_{bb}^{O,n}$: capacity of ONU type *n*, expressed in terms of broadband subscribers

$\mathbf{A_{EFbb}}$: subset of *Flow Arcs* associated to the APON-FTTC network that carry broadband services

$cap_{ds}^{Z,n}$: downstream bit rate capacity of ODNI type *n*

$\mathbf{bd_s}$: downstream bit rate required by the service *s*

$\mathbf{bd_{s1}}$: downstream bit rate required by the service *1* (POTS requirement for this technology)

$cap_{us}^{Z,n}$: upstream bit rate capacity of ODNI type *n*

$\mathbf{bu_s}$: upstream bit rate required by the service *s*

$\mathbf{bu_{s1}}$: upstream bit rate required by the service *1* (POTS)

$cap_{nb}^{X,n}$: capacity of OLT type *n*, expressed in terms of narrowband subscribers

$cap_{bb}^{X,n}$: capacity of OLT type *n*, expressed in terms of broadband subscribers

$cap_{odni}^{X,n}$: number of ODNIs that can be controlled by the OLT type *n*

$\mathbf{pi_{ij}}$: number of existing copper pairs in the arc $(i,j) \in A_M$

$\mathbf{pc_{ijp}}$: capacity (in number of copper pairs) of the cable type *p* whenever candidate in the arc $(i,j) \in A_M$

$\mathbf{fdc_{ij}}$: "availability factor" that gives the desired slack (non utilised copper pairs) in the arc $(i,j) \in A_M$

– *Interdependency Constraints:* guarantee that an ONU is allocated to an *Access Node* if and only if the APON-FTTC technology is adopted in the node:

$$B \cdot W_i - O_{ijn} \geq 0 \ , \ \forall i \in I_F \ , \quad \forall j \in J_1 \ , \forall n \in N3_{ij} \tag{14}$$

Where:

B : big integer number (actually, the maximum number of ONUs that can be allocated to an *Access Node*)

– *Additional Constraints:* they are associated to the modelling of technological functionality and privileges, as well as network topologies and security/reliability aspects. They are also used for managing the services' meeting. For example, in order to respect minimum and maximum demand-meeting levels, we may write:

$$Y_{si} + Y_{sj} \geq dmin_{sij} \ , \forall s \in I_S \ , \ \forall ij \in I_{FM} \quad (15)$$

$$Y_{si} + Y_{sj} \leq dmax_{sij} \ , \forall s \in I_S \ , \ \forall ij \in I_{FM} \quad (16)$$

Where:

$\mathbf{I_{FM}}$: set of the *Access Nodes*, whose parts *i* and *j* refer to APON-FTTC ($i \in I_F$) and copper network ($j \in I_M$)

$\mathbf{dmin_{sij}}$: minimum demand for the service *s* at the access node $ij \in I_{FM}$

$\mathbf{dmax_{sij}}$: maximum demand for the service *s* at the access node $ij \in I_{FM}$

Though the presented model is devoted to the xDSL *versus* APON-FTTC competition, it can be modified in order to deal with other technologies. Also, we shall note that the criterion can be changed by placing the budget constraint (2) as the cost to be minimised.

3. APPLICATION

3.1. General Data

A network based on actual data is used as application example. It corresponds to a CO area of a residential neighbourhood in a Brazilian metropolis (Fig. 4). There are 11,900 potential subscribers. The network's current capacity (only copper cables) is 8,100 subscribers. At each access node, the demand values for the ISDN, ASB and SSB services are calculated by multiplying each service's penetration level by the total number of subscribers at the node (demand). POTS' penetration level refers to subscribers that are not interested in another service. The adopted annual tariffs, presented in relative values, and minimum demand meeting values are listed in Table I. Data for xDSL and APON-FTTC technologies, such as supported service, equipment capacity (modularity) and costs, are in Table II.

TABLE I
Services' Data

Service class	Annual tariff	Minimum meeting
POTS	0.120	60 %
ISDN	0.344	55 %
ASB	0.800	50 %
SSB	1.800	65 %

TABLE II
Equipment Data of APON-FTTC and xDSL Solutions

Equipment	Supported service	Capacity	Cost (monetary units)
ADSL	ASB	1 x 2 Mbps (asymmetric)	1.000
HDSL	SSB	1 x 2 Mbps (symmetric)	1.000
ISDN Set Box	ISDN	1 x 144 kbps (symmetric)	0.400
OLT	All	10,000 narrowband subscribers 2,500 broadband subscribers	231.250
ODNI	All	600 Mbps downstream 150 Mbps upstream	4.000
ONU	All	128 narrowband subscribers 32 broadband subscribers	1.025

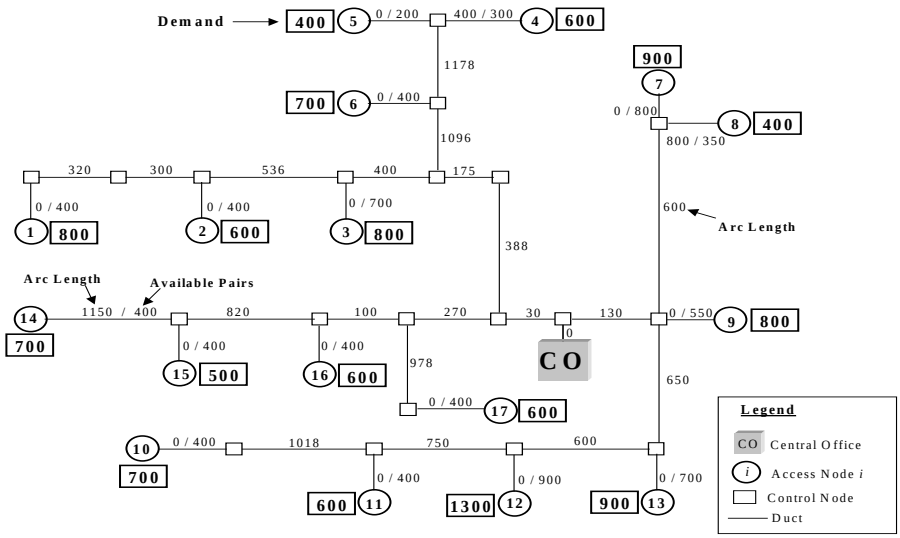

Fig. 4. Analysed network.

3.2. Scenarios and Analysis

In order to evaluate the effects of dropping equipment prices as well as of varying services' penetration levels, we studied several settings. Table III lists the input data used in five of them. It is assumed that 50% of existing ducts are available. Copper cables require a minimum slack of 20%.

A budget was stipulated to each instance. Table IV displays results obtained while searching maximum income configurations. We can observe the changes due to distinct ways of using candidate technologies for meeting the demand. Also, we can see that the income grows along with the increase of broadband services' penetration levels, even in situations where the budget is "tight" and the total number of subscribers effectively served is reduced. We shall also observe that the income/cost ratio increases from instance A to instance E. In instance B, in which APON-FTTC starts to be used, the income/cost ratio (1.75) is remarkably greater than instance A's (1.17).

In instance A, where the solution is entirely copper-based, both ISDN and ASB services are at their minima meeting levels. SSB service does not present a good performance as well. As long as APON-FTTC technology is chosen, broadband services become more interesting. The meeting of these services stays closer to their maxima in almost all instances, while the meeting of narrowband services remains at a low level: ISDN service is carried only by copper, and POTS' unmet demand increases (again, the copper network is the main responsible for carrying POTS).

The APON-FTTC network serves all the users of broadband services. Exceptions are instance A (an entire copper-based network) and instance D, which has 125 subscribers SSB served by modems HDSL. This decision is highly influenced by the modularity of the APON-FTTC equipment localised at CO.

TABLE III
Analysed Instances

	Instance				
	A	**B**	**C**	**D**	**E**
Service Penetration Level (%)					
POTS*	95.0	93.4	84.6	76.6	67.5
ISDN	2.5	2.8	6.0	9.8	13.3
ASB	0.5	0.8	1.9	3.1	5.2
SSB	2.0	3.0	7.5	10.5	14.0
Dropping of Equipment Price (%)					
	0	10	20	25	30
Budget (monetary units)					
	1,000.0	1,150.0	1,500.0	1,800.0	2,100.0

** Only POTS*

TABLE IV
Meeting Configuration and Income

	Instance				
	A	**B**	**C**	**D**	**E**
Copper network + xDSL (subscribers)					
POTS*	11,179	9,358	7,941	6,739	5,888
ISDN	173	195	410	809	878
ASB	36	0	0	0	0
SSB	190	0	0	125	0
APON-FTTC network (subscribers)					
POTS*	0	867	1,116	372	665
ISDN	0	0	0	0	0
ASB	0	97	228	370	606
SSB	0	357	896	1,128	1,666
Total met demand (subscribers)					
	11,578	10,874	10,591	9,543	9,703
Income (monetary units)					
	1,171.8	2,014.3	3,023.0	3,683.0	4,572.0

** Only POTS*

Fig. 5a presents the network configuration for the instance A. For each access node, it indicates the met demand (the amount of users) as well as the cable to be installed. The network is totally copper-based. Due to the constrained budget, access node 08 did not receive any new cable, and the existent copper cable meets its demand.

Fig. 5e shows the result for the instance E. For the access nodes, it presents the cables to be installed and the demand to be met by each one of the technologies. In situations with high penetration of the broadband services, we can observe the predominance of the optical network. Moreover, we can see that migration from the copper- to the optical-based network starts at the nodes whose distance to the CO is the greatest (see also Fig. 4 and Fig. 5c).

4. CONCLUSION

This work proposes a methodology that takes into account these current telecommunications features. The model allows competition between optical- and copper-based technologies, focusing on the income maximisation.

We reported the application of the methodology to a network of a Brazilian's city. We studied the network evolution in order to provide four types of services: POTS, ISDN, ASB and SSB. Two applicable, contending technologies were evaluated: copper network (with xDSL) and APON-FTTC. We inspected several scenarios, each of them with a setting for technology costs, services' penetration levels and budget constraint.

The results we obtained are a mix of the two technologies. Under the data structure we utilised, xDSL technology proved to be suitable to scenarios with low penetration of broadband services. Conversely, APON-FTTC was the most attractive technology in scenarios with higher penetration of broadband services. From the income point-of-view, the SSB service seemed to be the more "interesting" service. POTS, due to its high demand and massive use of the existent copper network, was also a "good income" service.

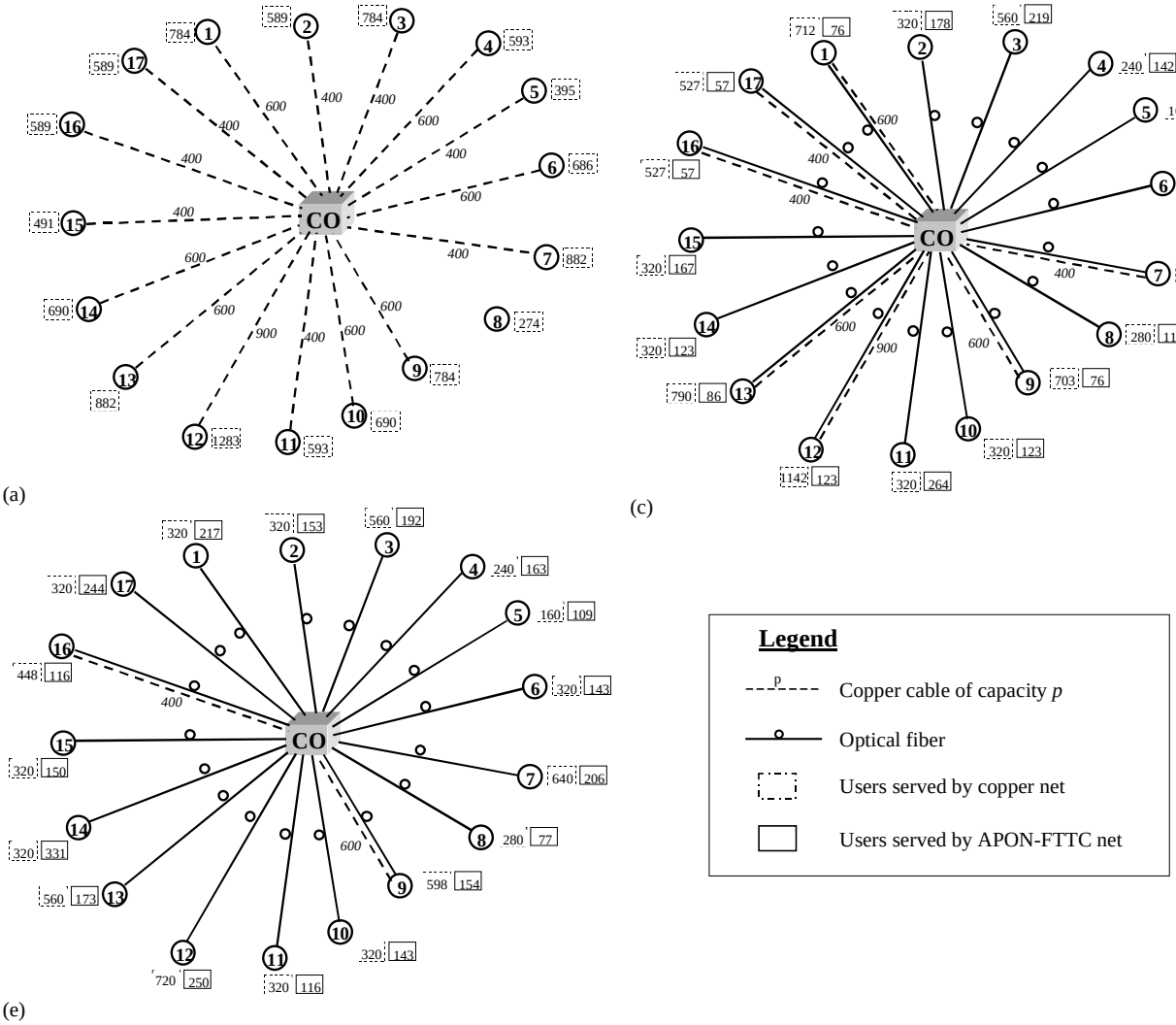

Fig. 5. Networks for the instances A (a), C (c) and E (e).

The proposed income-maximisation model allows realistic and flexible network considerations. A planning tool developed according to this methodology would be useful under two perspectives. First, to help equipment manufacturers to foresee the general impact of adding new services and functions in their products. Second, to assist service providers in searching low-cost network projects while both selecting services and assuring that the income is as large as possible. New prospective studies in order to achieve a complete understanding of the current market competition between incumbent and competitor operators may also be carried by each of these players.

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