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A Framework for Planning a Unified Wired and Wireless ICT Infrastructure

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Abstract—The increase in the use of information and communication technology (ICT) has pushed the existing access networks to their limits. Whole new access networks are currently being deployed and are expected to take full advantage of the already started synergy of services converging on to one network. Through a brief survey of synergy and technology trends, it is concluded that a future network will complementary use of wired and wireless technologies. In this context the paper proposes a framework for planning of unified wired and wireless ICT infrastructures. The framework includes different input parameters of relevance for the planning and implementation, which also include a step-wise implementation plan. Planning methods for wired and wireless planning is presented and a simplified large-scale case study is conducted to verify and illustrate the use of the framework.

Keywords—Wireless Access, WiMAX, FTTH, Broadband Networks, Network Planning, ICT infrastructure, Modeling

I. INTRODUCTION

Most of the world have experienced a large increase in the use of information and communication technology (ICT) for almost every possible purpose (for a Danish perspective - see [1]); from electronic mail, online shopping, and gaming to citizen service, remote control, and telemedicine. This development has triggered the penetration of increasingly faster broadband connections [2], and thereby greatly increased the load on the existing ICT network infrastructure and pushed it towards its limits.

Upgrades are currently being carried out on the access network, unlimited bandwidth. And so, for the first time in 100 years, a completely new media is about to be deployed in the wired access networks in a large number of countries on the initiative of governments, telcos and other market players. At the same time new wireless networks are also being deployed for both fixed and mobile access as the development in wireless technologies is emerging into still higher bandwidths and ranges.

Most of the old telcos are offering both wired and wireless network coverage. Currently the wired coverage is mostly offered through the old copper-based PSTN or CATV networks, where most, if not all, of the PSTN networks, used for POTS and ISDN, are owned by the former telephony monopolies, which have also taken a large share of the CATV networks, while the remaining CATV networks are owned by local or regional communities. The CATV networks are closed for competition, while the POTS networks are regulated and thus open for competitors, who can lease the raw copper and co-locate equipment on existing central offices or offer a connection through bit stream access, where the user traffic is delivered to a point in the operator's network. The network connection delivered by xDSL and even though high bandwidths can be delivered it is limited to the customers close to the central office.

New deployments by market-newcomers are being carried out both with respect to wireless and wired networks. Most noticeable is the ongoing effort by newcomers to deploy Fiber to the Home (FTTH), but WiMAX implementations in larger cities are also more and more often announced. A case study of broadband

infrastructure in the region of Western Greece can be found in [3] where both wired and wireless solutions are discussed separately.

For a majority of the new FTTH network operators the end goal is clear: To provide a 100% FTTH coverage. The time horizon for this goal is often relatively short¹.

It must be expected to be of the utmost importance for FTTH newcomers to have a rather high penetration rate in order to keep the customers satisfied and to win customers from day one. Due to the fundamental nature of digging down fiber, where especially the digging is a time consuming task, it can be relevant to consider others steps and approaches. Such could include buying in on existing wired or wireless networks, leasing or roaming on existing networks, or to consider other technologies than fiber, e.g. wireless, for a transition phase and/or as a complementary technology for the end scenario.

From the possibilities listed, the latter is the most appealing. Not only will it be much faster to deploy a wireless network, but it will also balance out the advantage of being able to offer a full package containing wired and wireless coverage, currently possessed by existing network operators. However, taking this approach will require an even more significant planning task than the planning of a wired network. Not only will the end goal be extremely important, but also the individual steps of going there will be of high importance.

In relation to the just mentioned considerations, this paper will present a framework for the stepwise planning of a unified wired and wireless network for FTTH newcomers. The framework will be useful as a more structured approach to network planning and will make it possible to further enhance the inclusion of more sophisticated planning methods along with different aspects, such as an overall business plan.

The remaining paper will first include a survey of the current trends within technologies and network synergies to further setup a basis for the subject considered. In section III the inputs for a planning model are considered, followed by description of the individual implementation steps in section IV. Afterwards the planning model will be surveyed and a case study conducted, followed by results, conclusion and discussion.

II. SYNERGY AND TECHNOLOGY TRENDS

Traditionally, the different ICT infrastructures have been dispersed into several big and small segments, ranging from fixed telephony, cellular networks, broadcast wireless networks: TV and Radio, cable TV, surveillance etc. Over time these networks have been diverging, converging, but mostly coexisting more or less independently of each other. In general the networks have been service-oriented - one network for one service and the networks have been specified in order to support for the services traversing it. The still increasing use of the Internet and thus IP (Internet

¹A Danish FTTH newcomer [4] is expecting to deploy 30,000 km of ducts filled with 18 million km of fiber within 6 years (around 14 km duct/day and 8,220 km fiber/day).

Protocol) has introduced and opened for the basic possibility of synergy, where all services can use the same network. Now the question is; if a network, using a single protocol is available and is able to offer all kind of services then why are all these different kinds of networks necessary, why not just have one network that is able to fulfill all the requirements of the services. The answer is that it all mainly come down to the limitation of technology itself.

When considering the future, the technologies in front within wired and wireless respectively are; FTTH and 4G wireless network. FTTH will be replacing the cooper networks, and 4G will evolve from existing wireless technologies. FTTH promises a scalable incomparable bandwidth, while 4G basically will be a network of networks, capable of using multiple wireless technologies simultaneously [5], [6]. There are two main wireless broadband technologies generally known as: 3G and WiMAX. 3G is a successor of the previous cellular networks e.g. GSM, iDEN, IS-95, GPRS etc., and WiMAX (802.16x) is the successor of WiFi (802.11x). The latest standards for WiMAX are 802.16d-2004 for fixed access with a typical coverage of up to 50 km, and 802.16e-2005 which includes mobility and provides 70 Mbps within a range of 3 to 8 km [7].

Whichever technology will be dominating in the wireless segment it is clear that it will be an integrated part of a wired infrastructure. Like today most of the users already have wired and wireless networks at the same time for different services, and in the future this phenomenon will remain alive unless some very unusual breakthrough hits which totally outperforms the wired segment. The infrastructure of the future is thus not be either wired or wireless, but rather wired and wireless as complementary technologies for the greater good of the user.

III. MODEL INPUTS

Before considering the actual implementation steps, it is necessary to consider the physical constraints forming the inputs for the model.

This include: Technology, geography, implementation and customers. In the following the inputs will be described along with the individual parameters of importance for the inputs.

A. Technology

An essential parameter is the bandwidth offered per customer, as it explicitly influence the lifetime of a given technology. The bandwidth should be sufficient for a time frame of at least the depreciation period of the equipment. Influence on bandwidth from distance, interference, overhead, shared media etc., especially relevant for wireless technologies, should be parameterized and the effects studied for the considered area to give an exact measure of the impact on a given technology.

The coverage of the access technology is also an important parameter as it directly influence the number of central offices or base stations in an area. The lower the coverage range the higher the number of such points to reach all customers.

For a wireless network, the mobility must also be considered along with the complete cost for deploying the technology including both the initial and the operating expenses included.

A lot more parameters exist and all relevant parameters must be considered. When surveying technologies, it is not likely that one technology will be the better option with respect to all parameters, as parameters will contradict with each other e.g. bandwidth versus mobility. The parameters must thus be weighted according to their relevance for the specific area, to choose the best technology.

1) *Network Architecture:* With respect to technology it is also relevant to consider the network architecture used. In this paper, a hierarchical network architecture is proposed. The architecture defines how the different network elements should be interconnected.

The hierarchical level can be found as organized in various ways and depends on the technology and the network requirements.

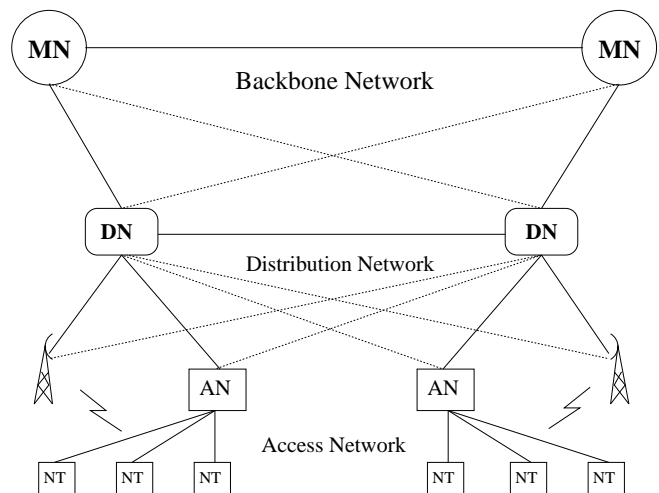


Fig. 1. The proposed network architecture.

The proposed architecture, shown in Figure 1, ensures redundancy at all the hierarchical levels. The distribution nodes (DN) are connected using two independent paths to two different main nodes (MN). The network must be able to survive not only in case of line failures but also in case of node failures. In the next level of the hierarchy the access nodes (AN) (or central offices as used in this paper) are connected to the distribution nodes. The access nodes also include base stations for the wireless access. The principle is the same as the previous hierarchical levels; all the access nodes are to be connected to the upper hierarchical levels with line and node independent paths.

B. Geography

The geographical area to be planned is of course a very important parameter and together with the customers, this is making up the demography. The geography is also of importance when choosing technology and considering the price. For the wired part mostly the price is influenced by the geography as the digging cost can be greatly increased if the underground is made up of rock or if a lot of rivers and streams are to be crossed. For a large geographical area with a low number of scattered customers, the maximum range can also be subject to consideration. For the wireless part the geography can influence parameters such as attenuation, fading and reflection effects etc., which is most likely to be of importance if considering dense urban areas, areas with mountains or forests etc. As with the wired technology, cost will be influenced by the geography, mainly because of an increased number of base stations.

C. Implementation

The inputs from the implementation, mainly cover boundaries set up by the business case. These inputs include the time frame for building the new infrastructure, the resources available and the spread of the implementation.

D. Customers

Providing services to customers is the basic condition for the existence of a network. The type of customer, and the difference between customers of the same type, vary greatly; e.g. from sensors to HDTV consumers.

Each customer is prioritized in order to decide on the order of connectivity - the higher the priority, the sooner the customer is connected. The priority is calculated as a function of various parameters, illustrated through Figure 2.

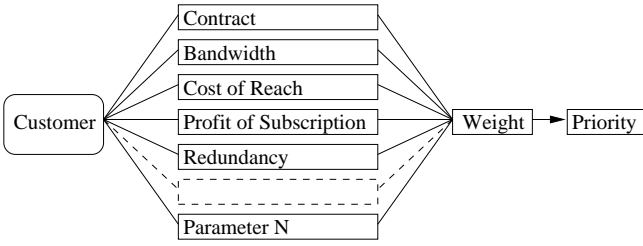


Fig. 2. Setting up parameters for each customer and calculating the priority.

Many parameters exist, but they are not equally important. If the customer has or is part of a contract specifying an actually latest time of connectivity, this should obvious increase the priority of the customers.

Providing redundancy comes at an extra cost, which does not only cover the extra line or antenna needed to give the customer two connections. Redundancy has to be insured all way through the upper level networks by having nodes and lines independence between the two paths on the logical as well as the physical layer. The impact on priority is thus a matter of time. If a fully redundant backbone has been implemented, the redundancy will be balanced with the extra subscription fee charge for the service. If, however, at the given time redundancy has not been implemented, the cost is greatly increased as not only the extra access line has to be established, but also lines and nodes in the upper level networks.

IV. IMPLEMENTATION STEPS

The implementation of a new ICT infrastructure will be divided in three steps: Operational, Tactical, and Strategic. In each step, the synergy between the different network levels is utilized in full (see e.g. [8] for the significance of synergy in the access network). Whenever a certain trace for one of the network levels has been dug up, the capacity needed in this trace for the other network levels, is included as well (at least in term of empty tubes).

A. Operational Step

The operational step includes the essential task of building a core infrastructure to be the backbone of the network about to be built.

Full redundancy is not needed at this stage, why focus is on connectivity. However, the connectivity is provided in order to eventually support a structure (such as a grid [9]) that can provide good properties with respect to Structural Quality of Service (SQoS) [10]. The number of fibers for each line are deployed in a magnitude able to support the traffic in a time frame at least equal to the span of the three steps, when considering the rapid development in capacity available through upgrade of end-equipment.

High priority customers will also be connected at this step and depending on the customer priority the connectivity should be offered as a wired or a wireless connection. If the high priority customers are requiring wired redundancy, the number of central offices are kept down by establishing the longer wired connection for a part of the customers. A number of base stations are established to increase the number of customers. The base stations are located to maximize the number of customers reached, considering the bandwidth available. For the customers requiring redundancy, the secondary connection is offered through wireless and this is also included in the location of the base stations.

B. Tactical Step

The core infrastructure is upgraded for redundant connections, to end up in the structure decided on. If the core lines were

not initially setup to support the traffic load in this step, end-equipment is upgraded to support the current and future load. A complete wireless network is deployed in order to reach the whole area. Customers are connected to the wireless network, as long as sufficient bandwidth is available. Priority customers are offered redundancy through either the wired or the wireless network. Customers from base stations, which are getting overloaded, should be given higher priority in order to offload the wireless network.

C. Strategic Step

In the strategic step all customers are gradually connected with a wire with respect to their priority and bandwidth considerations, for their primary connection, can be discarded.

Wired redundancy is established to all customers requiring it.

The wireless network is now present as a redundant connection. All customers will thus have two independent connections and some customers will have three independent connection, virtually eliminating all downtime. Furthermore the wireless connection will still function as a dedicated access network for mobile users, and will thus offer extra service to the customers.

V. PLANNING MODEL

To plan a network a planning model is essential. There are two main categories, namely wireless planning and wired planning. In this paper the focus is on an overall planning rather than a detailed planning, why the planning will not focus on strict optimization since the aim is to give an overall overview of a combined wired and wireless network infrastructure. Traditionally, planning has been carried out manually in an ad-hoc manner and wired and wireless infrastructures have been planned separately.

A. Wired Planning

For the wired part a GIS based automated planning model, as proposed in [11], will be employed, which gives some systematic approaches to network planning.

Planning the wired part is relatively difficult when planning at large scale. In theory wires can be placed anywhere, but in reality it is not the case. Buildings, houses, mountains etc. can be obstacles when deploying the cables. One of the planning requirements is to find the potential places where central offices can be located and where cables can be placed confronting minimum obstacles. When looking at the real world the most used sites are road networks. Roads are means of interconnecting places for transportation and often have a shortest distances. For the modelling purpose roads could be a better choice for the potential sites for cable placement. Today, GIS data is easily available for many parts of the world. GIS data provides a road network in digital form.

B. Wireless Planning

For the wireless part GIS information is also used to determine the number of base stations needed and two main parameters are considered: coverage and bandwidth. An overall estimation is required to find out how many base stations are needed. The locations for the base stations and coverage are determined through an algorithm containing the following steps.

Step 1 For the starting step, a square/cell is created covering the considered area. This can be done using two extreme points of a square; either bottom right and top left or vice versa. These two reference points are also useful to determine the number of customers and the locations for the base stations.

Step 2 The squares are split into two smaller cells, and this splitting function continues recursively until the distance parameter is satisfied. In addition, the split predecessor cell is removed.

Step 3 The cells are further split if needed along with satisfying the number of customers in the given cells. Since the base station has a limited bandwidth capacity available, the size of the cell is mainly dictated by the number of customers within the cell.

Step 4 The cells with a low number of customers which are within the coverage of neighbor cells are removed - the neighbor cells should have sufficient capacity to include the customers from the cell which is being removed.

The model does not consider other parameters like attenuation, fading and reflection effect etc.

VI. CASE STUDY

To investigate the usefulness of the model a case study has been conducted and will be described in the following. The purpose of the case study is also to further illustrate the use of the model.

A. Model Inputs

For the case study, the inputs for the strategic planning model are needed. The following determines the inputs based on the general framework given in section III.

1) *Technology: (Wired)* - FTTH access technology is used for the wired network and it is considered to be offered as a homerun solution giving 1 dedicated fiber from the customer to the central office.

Bandwidth is considered to be virtually unlimited and can already be offered as 100 Mb/s or 1 Gb/s. The homerun is also very scalable, as multiple wavelengths can be used later on to increase the bandwidth capacity of a single fiber. Furthermore the reach can easily be up to 10 km and further increased by choosing quality components and carefully handling the fiber and splices or in extreme cases to add in optical amplifiers.

(Wireless) - For the wireless part, a WiMAX 802.16e solution has been chosen. 802.16e is the latest standard and is already being deployed in many parts of world.

WiMAX 802.16e offers a bandwidth in the order of 70 Mb/s per base station and the reach is up to 8 km, which is decrease to 5 km considering the bandwidths needed.

For the case study a required bandwidth of 10 Mb/s per customer has been considered together with a 10% penetration and a 10% utilization, adding up to 700 potential customers per base station.

2) *Geography:* As a case study area, the county of North Jutland has been chosen. The county [12], with a population of 495,068, is one of the most rural areas in Denmark covering 6,173 km², giving a population density of only 80 citizen per km².

This region does not setup special geographical considerations to be taken. However, if considering the higher level networks and line independence, the fjord traversing the region can put up challenges. As Denmark is a rather flat terrain country, meaning it does not have higher elevation such as mountains etc., wireless planning is done without any consideration to other parameters than reach and bandwidth.

3) *Implementation:* The time frame of the case study performed is expected to be 15 years, with the operational step to be completed in 3 years, the tactical step in 5 years and the strategic step in 15 years. This is considered together with a full spread implementation, meaning a full roll-out of all central offices and base stations. It is presumed that the economics and workforce will be available.

4) *Customers:* For the case study, a full range of customer types is not considered. The customer types considered are types where direct interaction is taking place with human beings. This choice has not been made because the authors neglect the importance of control of power plants or traffic light, but first of all because such tasks are likely to setup demands more suitable for a dedicated

network and secondly because the attended audience of this paper (FTTH newcomers) are not focusing on such types of customers.

Based on the former considerations, the different customer types can be defined and prioritized according to the parameters described in section III-D.

(Public) - public institutions are considered high priority customers, as they are likely to have contractual agreements of delivering of network coverage. They can be expected to be on long term leases and to have a well-defined usage pattern. Public institutions are considered redundancy-dependent, as e.g. hospitals are included in this category. For the case study area this amounts to 2,147 potential customers.

(Business) - businesses are also considered high priority customers. For certain large companies, contractual obligations can exist e.g. to connect branches of a company. Redundancy must also be considered for this category especially when considering the increasingly use of IT in businesses, not to mention e-commerce. The business category includes 5,599 customers.

(Private) - private customers are by large the biggest amount of the customers, however, they are only considered at a medium priority. First of all the penetration rate is not easily determined as no contracts are likely to be agreed upon before start of the deployment. Related to this, the private customers are not likely to agree upon long term leases with the operator and they are more likely to change to another operator if a good offer is available. Lastly, the individual bandwidth requirement for this type of customers is low compared to a business or public institutions. This category includes the remaining 284,016 customers in the area.

B. Implementation Steps

For the case study the implementation steps for the deployment of a combined wired and wireless infrastructure will be as listed in the following.

1) *Operational Step:* In this step every public institutions and business will be offered connection through FTTH. This is enough to fulfill the requirements with respect to bandwidth.

Furthermore, a full wireless coverage is offered through the deployment of a full range of WiMAX base stations. The base stations are fed by a single fiber wired connection. All customers are offered wireless connectivity and the WiMAX network will also be working as a second redundant connection for public institutions and businesses.

2) *Tactical Step:* The tactical step connects all customers within a radius of 2 km from central offices with a FTTH connection. At the same time all public institutions are given a wired redundant connection. The same is the case for the WiMAX base stations.

3) *Strategic Step:* In the final step all customers are offered connectivity through a FTTH connection. The business customers are given redundancy through a wired connection. The WiMAX network will then no longer have any primary customers and will function as a network used for mobile users in the area. As today it is becoming more common to use load balancing routers where multiple access connection can be used for backup and sharing. As such the two networks can both offload each other and be each other redundant path, seamless to the customer.

C. Results

A complete unified wired and wireless network was planned for the case study area. The number of customers along with the fiber and digging needed can be seen from Table 1 for the individual implementation steps. The results for estimation the number of base stations need are illustrated in Figure 3.

	Customers	Fiber	Digging
Operational	8,512	19,737	2,547
Tactical	169,844	200,178	6,518
Strategic	284,782	715,712	12,911

Tab. 1. Number of customers plus needed fiber and digging [km] for the three implementation steps.

	Units	Cost/unit	Total
Pole and building	766	13,333	10.2
Electronics	766	33,333	25.5
Fiber 1st path [km]	1,972	0.13	0.3
Fiber 2nd path [km]	4,219	0.13	0.6
Total			36.6

Tab. 2. Extra cost of adding a wireless network (total prices in million Euros).

1) *Wireless - Extra Cost:* Even though this paper is not focused on detailed cost calculation of networks, it is highly relevant for FTTH newcomers to know the cost of deploying a wireless network. The prices considered have been obtained through [13] and an exchange rate of 7.5 DKK/EUR has been used. The cited report includes cost analysis for both initial and operating expenses, however, due to the large variation and uncertainty with respect to the operating expenses, only the initial cost has been included.

Deploying FTTH to all customers, implies that most of the road network will be used as basis for traces. In that case none or only very little extra digging will be needed for the WiMAX base stations. The cost of the wireless network is thus limited to the cabling needed to supply the base station plus the cost of setting up a base station, which includes buildings, poles, electronics and antennas.

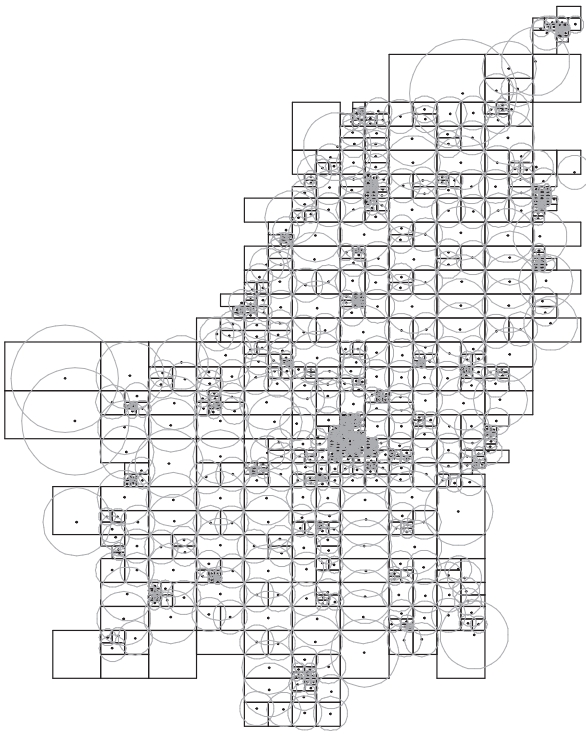


Fig. 3. Results from the wireless base station estimation.

The costs can be seen from Table 2, which does not include the equipment on the customer's premises (around 700 Euro). If

not deployed as part of a wired roll-out, digging will be needed in order to feed the base stations. For the case study considered that would add up to about 1,518 km if a single connection is considered sufficient and 3,109 km if redundancy is added.

For a prioritized deployment to cover many customers fast or if a full wireless coverage is not needed, it is relevant to consider, which base stations to deploy first.

VII. CONCLUSION

In this paper, a framework for planning of combined wired and wireless ICT infrastructures has been proposed. The framework considered different input parameters that could setup limitations and boundaries for the implementation, including technology, business models, geography and prioritizing customers. As part of the framework three implementation steps were included; the operational, tactical and strategic step. Based on the framework, a simplified large-scale case study was carried out, including almost 300,000 customers. The conclusion on the case study was that the framework was useful.

The overall conclusion is that to take full advantages of the synergy of services converging on to one network, wired and wireless must be considered as complementary technologies and considered as such throughout the planning and implementation of a new ICT infrastructure. On the lower level the inclusion of more parameters for network planning is concluded to be most useful, especially the inclusion of business models and the step-wise implementations both with respect to time and customer priority.

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