

A Framework for Planning a Unified Wired and Wireless ICT Infrastructure

Riaz, M. Tahir; Nielsen, Rasmus Hjorth; Pedersen, Jens Myrup; Prasad, Neeli R.; Madsen, Ole Brun

Published in:
Wireless Personal Communications

DOI (link to publication from Publisher):
[10.1007/s11277-009-9720-5](https://doi.org/10.1007/s11277-009-9720-5)

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):
Riaz, M. T., Nielsen, R. H., Pedersen, J. M., Prasad, N. R., & Madsen, O. B. (2010). A Framework for Planning a Unified Wired and Wireless ICT Infrastructure. *Wireless Personal Communications*, 54(1), 169-185.
<https://doi.org/10.1007/s11277-009-9720-5>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

A Framework for Planning a Unified Wired and Wireless ICT Infrastructure

M. Tahir Riaz · Rasmus H. Nielsen · Jens M. Pedersen ·
Neeli R. Prasad · Ole B. Madsen

Published online: 1 April 2009
© Springer Science+Business Media, LLC. 2009

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 fully support 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 use wired and wireless as complementary 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. The framework is concluded to be useful and the discussion lists some areas for further consideration.

Keywords Next generation networks · Network planning · Convergence · WiMAX · FTTH

M. T. Riaz (✉) · R. H. Nielsen · J. M. Pedersen · N. R. Prasad · O. B. Madsen
Section for Network and Security, Department of Electronic Systems,
Aalborg University, Niels Jernes Vej 12, A5-209, 9220 Aalborg, Denmark
e-mail: tahir@es.aau.dk

R. H. Nielsen
e-mail: rhn@es.aau.dk

J. M. Pedersen
e-mail: jens@es.aau.dk

N. R. Prasad
e-mail: np@es.aau.dk

O. B. Madsen
e-mail: obm@es.aau.dk

1 Introduction

Most of the world has 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 telehealth. 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 last mile access link between the customer (a network terminal) and the telecommunication company's central office—the access network. As a result many countries are in a transition phase in which the current 25–100 year old copper cables are being replaced by fiber optics with virtually 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, telecommunication companies 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 telephony companies 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 is xDSL and even though high bandwidths can be delivered it is limited to the customers close to the central offices.

With respect to wireless services the competition is more open, since no company has been given a network through a period of monopoly. This is seen from the number of independent wireless networks and the even broader span of companies offering wireless services through complete or partly roaming on existing networks.

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 for a certain area. The time horizon for this goal is often relatively short.¹ The reasons for the short deployment times can only be guessed as it must be expected to cover more than just the good-hearted intention of providing fast network access to the citizens or bring certain areas in the lead of the broadband evolution. For many consumer-owned companies the deployment rate is dictated by an effort to try to keep the customers satisfied and furthermore not differentiated between the customers. In a Danish context, the recent sellout of shares in the power production company ELSAM has rewarded the power

¹ A 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).

companies, why they are in a position to consider long term investments. In other countries some similar conditions, making it lucrative to deploy FTTH, must be expected to be present, whether it is regional or governmental initiatives or market powers. Another reason for a fast deployment is the old telephony monopolies which are not just standing on the side, watching their customers disappear.

No matter the reason, 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 and expensive task, it can be relevant to consider others steps and approaches. Such could include buying 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 Sect. 3 the inputs for a planning model are considered, followed by a description of the individual implementation steps in Sect. 4. Afterwards the planning model will be surveyed and a case study conducted, followed by results, conclusion and discussion.

2 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, CATV, 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 the services traversing it. The still increasing use of the Internet and thus IP 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.

To make it easier networks can be divided into two general categories: wired networks and wireless networks. For the wired networks a fixed location is a basic constraint, whereas wireless networks are flexible in this manner. Moreover, on the wired side, the communication media between two locations is a physical wire, and on the wireless side the communication media is just space. Thinking about the best media then the ideal would, no doubt, be wireless, where location is flexible and also the media is free of the physical constraint applying to the

wired network. The big advantage of wireless technology—the free media—is also its main downside, as the media is shared and the signals, in that way, are victims to various kinds of interferences. The wireless technology is thus limited capacity or bandwidth-wise as well as in distance, as the power sent out on the media must be controlled and limited for the greater good of all the wireless users. The wired technology is in general many times more efficient compared to wireless in terms of bandwidth. It is to be noted that the comparison is being made with the most advanced technologies at the present time. An example to consider with respect to bandwidth is the transition of broadcast wireless TV networks to the CATV networks. A similar example, considering transition from wired to wireless, is the cellular networks that are constantly eating the shares of PSTN. As the basic voice telephony does not require a high bandwidth, the wireless becomes more attractive as it provides mobility on top.

It can be summarized from the above discussion that wireless and wired technologies will coexist. The use will depend on the services which can be offered. The technologies will be competing each other within certain areas and complementing with each other within other areas.

When considering the future, the technologies in front within wired and wireless respectively are FTTH and 4G wireless network. FTTH will be replacing the copper 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 emerges which totally outperforms the wired segment. The infrastructure of the future is thus not to be either wired or wireless, but rather wired and wireless as complementary technologies for the benefit of the user. Taking this approach is also the only way to take full advantage of the synergy between networks, as neither wired or wireless is the best option for all services.

3 Model Inputs

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

This includes: technology, geography, implementation and customers, as seen from Fig. 1. In the following the inputs will be described along with the individual parameters of importance for the inputs.

3.1 Technology

For both the wired and the wireless technology, relevant parameters should be put up in order to determine the possibilities and/or limitations in connection with the implementations.

An essential parameter is the bandwidth offered per customer, as it explicitly influences the lifetime of a given technology. The bandwidth should be sufficient for a time frame of at

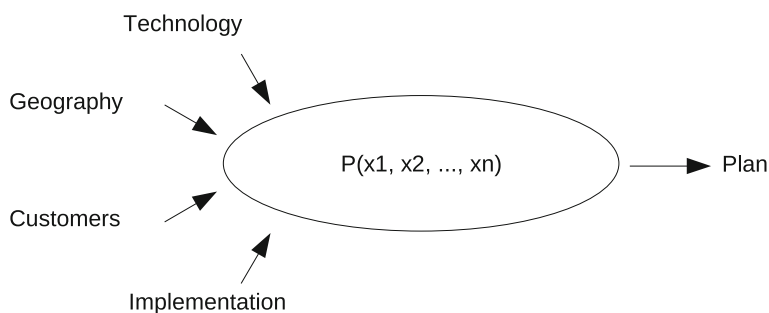


Fig. 1 Inputs for the planning function

least the depreciation period of the equipment. Influence on bandwidth from distance, interference, overhead, shared media etc., especially relevant for wireless technologies, should be parametrized 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 oppose each other e.g. bandwidth versus mobility. The parameters must thus be weighted according to their relevance for the specific area in order to choose the best technology.

3.1.1 Network Architecture

With respect to technology it is also relevant to consider the used network architecture. 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.

The proposed architecture, shown in Fig. 2, 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.

3.2 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 the price is mostly influenced by the geography as the digging cost can be greatly increased if the underground

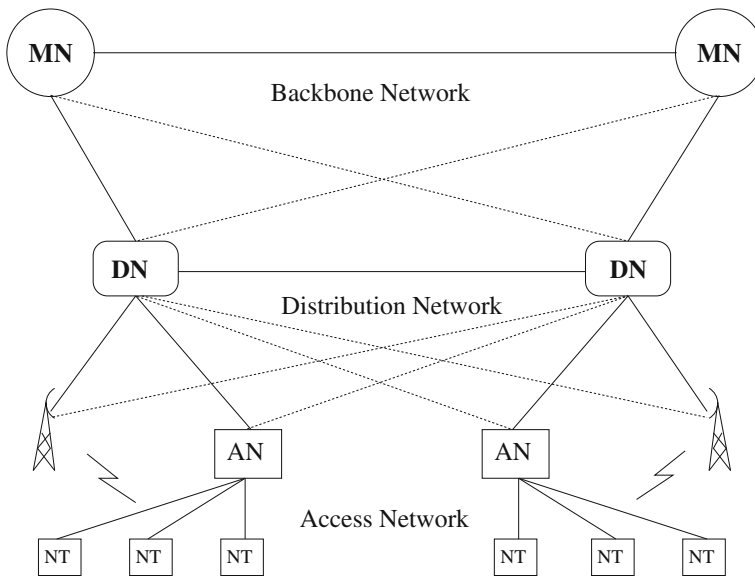


Fig. 2 The proposed network architecture

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.

3.3 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.

A figure for the time frame for the implementation is needed in order to project a realistic plan. The time frame is bounded below by the constraints formed by the resources. The number of customers connected within a certain time frame is limited by the amount of money invested in planning, documentation and deployment. A factor such as lack of the required amount of work hours relating to both planning and deployment is also likely to put up boundaries.

The spread of the implementation effort is also an important input parameter. The two extremes are either to start in one area only or to start in all areas at the same time and implement them concurrently. Both extremes are just as unrealistic. Different areas (defined through the closest node) can be seen independently, if disregarding the need for node-independent redundancy and frequency considerations. As such the individual areas can also be planned and, more importantly, implemented independent of the overall plan, giving the two possible implementation approaches mentioned above. Taking one or the other approach has different advantages and disadvantages when it comes to initial and operating expenses and the accumulated interest and depreciations. The expected penetration rate and especially the variance of it between different areas must be closely considered for this aspect.

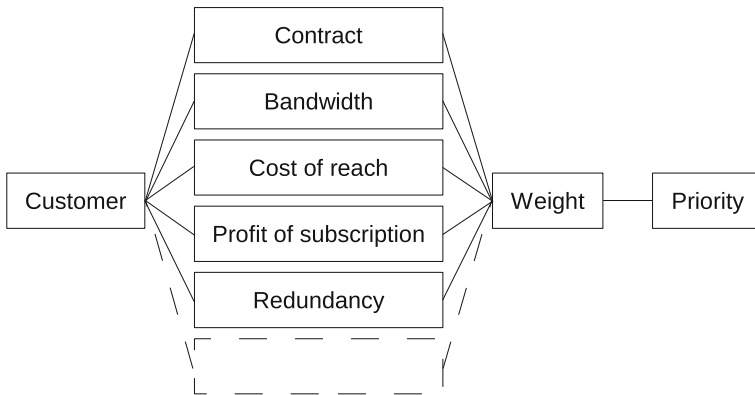


Fig. 3 Setting up parameters for each customer and calculating the priority

3.4 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 Fig. 3.

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 obviously increase the priority of the customers.

The current and expected bandwidth usage of a customer also influence the priority. However, the direction is diverse, depending on whether the customer is to be connected wired or wireless. In the wireless case, a high bandwidth customer can be undesirable due to the limited overall bandwidth, but on the other hand, it is very desirable to move such a customer from the wireless to the wired network. Depending on the customer type, it is not likely that knowledge of bandwidth consumption is available prior to subscription. If information of bandwidth is available, it will thus influence the priority in a negative or positive direction for not-connected and connected customers respectively. The effect of bandwidth increases over time as it becomes more and more crucial to offload the wireless network, due to the general trend of bandwidth increase over time.

The cost to reach a certain customer is also included as part of the priority. The cheaper it is to reach a customer, the higher the priority. This cost is not easily determined, as the cost should be seen throughout the lifetime of the complete network.

The profit generated by having the individual customers subscribing to the services is also to be considered. Combined with the cost of reach, this is what makes up the business case. The profit generated from a customer is most likely to be directly related to the services subscribed for and e.g. an one time fee charged for the service of providing the connection. In such cases it should be considered if customers can be differentiated and charged for the proportional cost of covering them. Add-on services such as redundancy or QoS guarantees are also included.

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.

4 Implementation Steps

The implementation of a new ICT infrastructure will be divided in three steps; operational, tactical and strategic. In every 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).

4.1 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 prioritized at this stage, hence 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.

If a full spread implementation approach has been decided upon all planned central offices are built and connected to the higher level networks. Otherwise only a limited number of central offices are set up and connected to the upper level networks. The specific number of central offices should be kept as low as the spread of the high priority customers allows.

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.

4.2 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.

4.3 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 connections, 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.

5 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.

5.1 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 Sect. 3.

5.1.1 Technology

In the following, technology has been divided into wired and wireless and will be described as such.

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 the world.

WiMAX 802.16e offers a bandwidth in the order of 70 Mb/s per base station and the reach is 5–8 km. 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.

5.1.2 Geography

As a case study area, the county of North Jutland in Denmark (see Fig. 4) has been chosen. The county [11], with a population of around half a million, is one of the most rural areas in Denmark covering 6,173 km², giving a population density of only 80 citizens 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

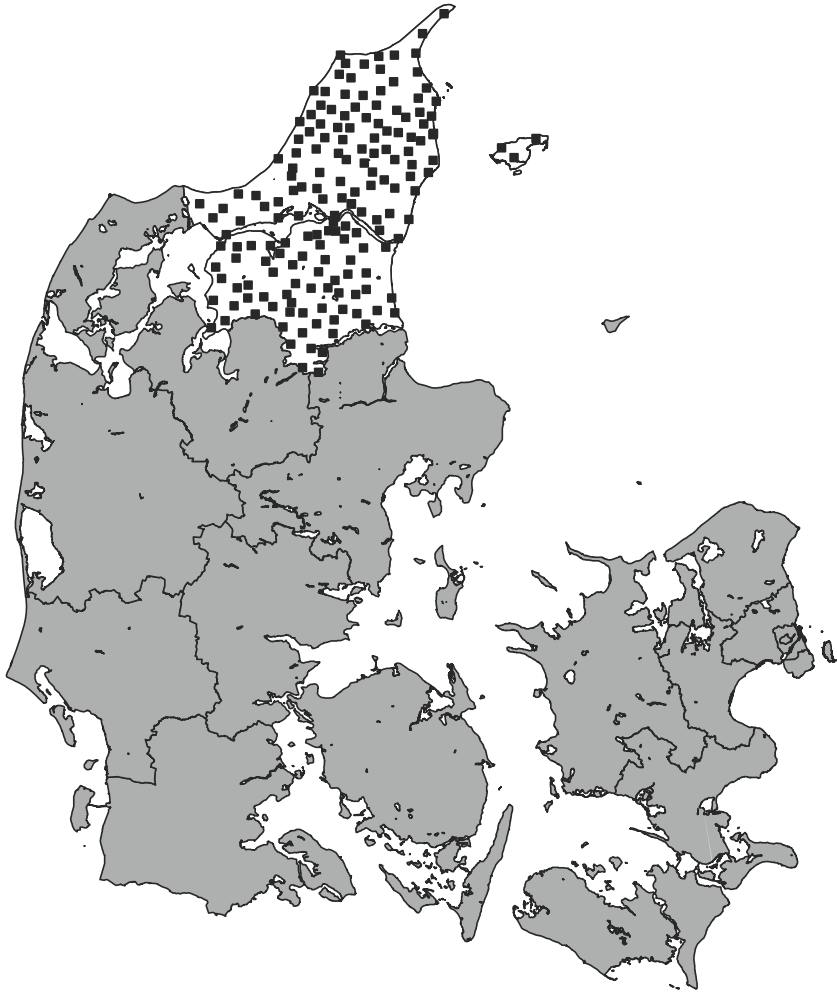


Fig. 4 The county of North Jutland with the used central offices

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.

5.1.3 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.

5.1.4 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 Sect. 3.4.

Public: public institutions are considered high priority costumers, as they are likely to have contractual agreements on deliverance 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 starting 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.

5.2 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.

5.2.1 Operational Step

In this step every public institution 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 wired single fiber connection. All customers are offered wireless connectivity and the WiMAX network will also be working as a redundant connection for public institutions and businesses.

5.2.2 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.

Table 1 Number of customers plus needed fiber and digging (km) for the three implementation steps

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

5.2.3 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's redundant path, seamless to the customer.

5.3 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 of estimating the number of base stations needed are illustrated in Fig. 5.

5.3.1 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 [12] 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.

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. Figure 6 shows the coverage of customers in relation to the number of base stations. It can be seen from the figure that the number of customers covered is increasing linearly with the number of base stations up to about 300 base stations. Hereafter the increase decays but is still linearly until around 500 base stations, from where the increase more assembles a logarithmic increase. If

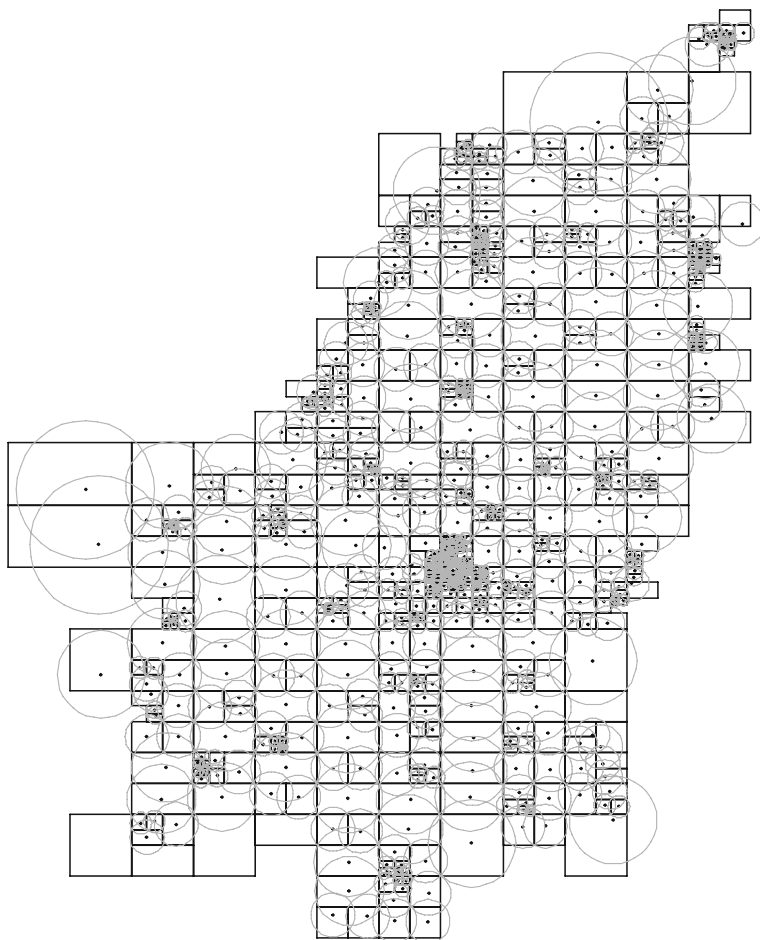


Fig. 5 Results from the wireless base station estimation

full coverage is not an end goal, it should thus be carefully planned, whether to place base stations beyond the 300 limit and especially the 500 limit.

5.4 Case Study Conclusion

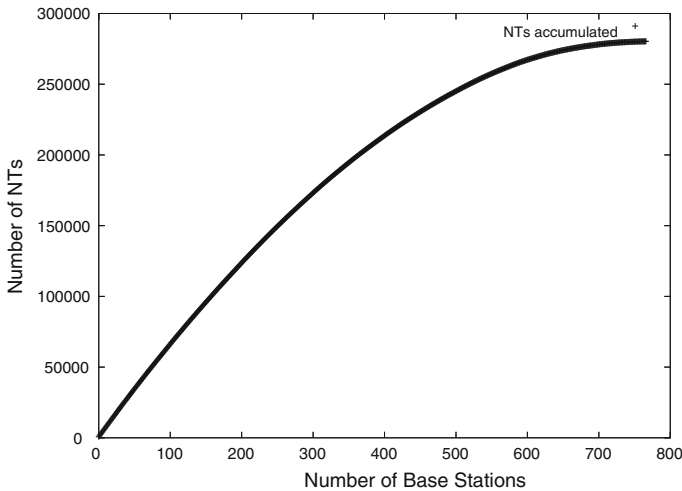
Based on the case study it is concluded that it is possible to combine the planning for wired and wireless technologies. The stepwise implementation has also been found useful and from the results given, it is concluded that a considerable faster roll-out in terms of customers can be performed when including a wireless technology.

6 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

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

	Units	Cost/unit	Total
Pole and building	766	13,333	10.2
Electronics	766	33,333	25.5
Fiber 1st path (km)	1,972	130	0.3
Fiber 2nd path (km)	4,219	130	0.6
Total			36.6

**Fig. 6** Number of customers in relation to number of base stations

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 implementation both with respect to time and customer priority.

7 Discussion

The case study assumed that the penetration rate would be 100%—that is; that every customer would sign up as soon as a connection was offered. This is not likely to be the case and as such the expected penetration should be included in the priority of customers to give the overall maximum profit.

For the wireless part, 802.16e was proposed and the solution offers not only none line of sight connectivity but also mobility. It is also likely that the future will bring some other wireless technology with better performance.

For further research, more optimization should be considered in relation to the planning model. At the same time the economical modeling should be enhanced in order to put up more realistic overviews of the economics involved in deploying different solutions.

The different customer types should also be more in detail considered, in order to further differentiate between customers.

References

1. Statistics Denmark. (2003–2006). The Public's Use of the Internet. <http://www.dst.dk/>.
2. National IT and Telecom Agency, Denmark. (1997–2005). Yearbook of Tele. <http://www.itst.dk/>.
3. Alexiou, A., Bouras, C., Igglesis, V., Kapoulas, V., Paraskeuas, M., Scopoulis, I., & Papagiannopoulos, J. (2005, October 3–7). Deployment of broadband infrastructure in the region of Western Greece. *Broadband networks, 2005 2nd international (broadnets 2005)* (pp. 35–42). Boston, MA: IEEE.
4. MidtVest Bredbaand. (2006, December). We are changing middle and western Jutland. <http://www.mvb.dk/>.
5. Ghosh, S., Basu, K., & Das, S. K. (2005). What a mesh! An architecture for next-generation radio access networks. *Journal of IEEE Network*, 19, 35–42.
6. Frattasi, S., Fathi, H., Fitzek, F. H. P., & Prasad, R. (2006, February). Defining 4G technology from the user's perspective. *Journal of IEEE Network*, 20, 35–41.
7. 802.16 Working Group. (2006, December). The IEEE 802.16 working group on broadband wireless access standards. <http://www.ieee802.org/16s>.
8. Nielsen, R. H., Jensen, M., & Madsen, O. B. (2006, February). Investigation of cost reductions through synergy effects when deploying commercial WANs. In *The 8th international conference on advanced communication technology (ICACT 2006)* (Vol. 3, pp. 2164–2167). Phoenix Park, Korea: NCA, ETRI.
9. Pedersen, J. M., Patel, A., Knudsen, T. P., & Madsen, O. B. (2006). Applying 4-regular grid structures in large-scale access networks. *Computer Communications*, 29, 1350–1362.
10. Madsen, O. B., Knudsen, T. P., & Pedersen, J. M. (2003, October). SQoS as the base for next generation global infrastructure. In *Proceedings of IT&T 2003, information technology and telecommunications annual conference 2003* (pp. 127–136), Letterkenny, Ireland.
11. StatBank Denmark. (2005). StatBank Denmark. <http://www.statistikbanken.dk/>.
12. NJNF. (2005, May). Broadband network on the country side near Jels. <http://www.midtlandsnet.dk/>.

Author Biographies



M. Tahir Riaz is currently an Assistant Professor in the Networking and Security Section at the department of Electronic Systems, Aalborg University, Denmark. He received his Master and Ph.D. degrees in electrical engineering specializing in network planning and design from Aalborg University in 2004 and 2008 respectively. He also holds a master degree, received in 2001, in Communication and Information Interactivity from Linköping University, Sweden. In 2001, he spent 6 months at Nokia, Linköping, Sweden working on Nokia media master 9800 product family. He is involved in the FUTON project (2008–2010), seventh framework programme funded by the European Commission on information society and media. He has authored or co-authored over 30 papers published in conferences and journals. His research interests include access and backbone fiber optic networks, network planning and design, architecture of next generation Radio of Fiber networks, reliability and QoS issues in global network infrastructures, and performance and optimization in large-scale network infrastructure.



Rasmus H. Nielsen received the master degree in electrical engineering from Aalborg University, Denmark, in 2005. He has specialized within optimization problems in planning of ICT networks and is currently pursuing an industrial Ph.D.-degree within this topic. Concurrently with his Ph.D.-work, he has been working as a network planner in NJNF, a Danish consultancy, since 2006 and as a partner since 2007. Through this work he has been commercially involved in a large number of planning projects in Denmark, responsible for tasks ranging from R&D to actual planning. He is the author or coauthor of a number of papers published at international conferences. His research interests include many topics within operational research for network planning.



Jens M. Pedersen is an Associate Professor in the Networking and Security Section at the department of Electronic Systems, Aalborg University, Denmark. He graduated from Aalborg University in January 2002, where he obtained his master degree in mathematics and computer science. In March 2002 he started as Ph.D. student at Aalborg University, Department of Control Engineering, where he is now since March 2005 working at Aalborg University. He has authored or co-authored more than 50 papers published in various international conferences and journals. His research interests include, graph theory, network planning and design, network architecture, reliability and QoS modelling, network performance and optimization.



Neeli R. Prasad is Associate Professor and Head of Wireless Security and Sensor Networks Lab, part of Wireless Network including Embedded systems Group (WING), Center for TeleInfrastruktur (CTIF), Aalborg University, Denmark. She received her Ph.D. from the University of Rome, Italy, in the field of “adaptive security for wireless heterogeneous networks” in 2004 and M.Sc. (Ir.) degree in Electrical Engineering from Delft University of Technology, The Netherlands, in the field of “Indoor Wireless Communications using Slotted ISMA Protocols” in 1997. She joined Libertel (now Vodafone NL), Maastricht, The Netherlands in 1997. From 1998 to 2001 she worked as Systems Architect for Wireless LANs in Wireless Communications and Networking Division of Lucent Technologies (now Agere Systems), The Netherlands. From 2001 to 2003 she was with T-Mobile Netherlands as Senior Architect for Core Network Group. From 2003 to 2004 she was Senior Research Manager at PCOM:13, Aalborg, Denmark. Neeli Prasad has published widely and has supervised several Masters and Ph.D. students.



Ole B. Madsen was born in 1942 in Denmark and received his M.Sc. in Mathematics & Computer Science from the University of Copenhagen. During 1962–1972 researcher and from 1968 head of the Computer Science Laboratory at The Royal Danish Academy of Fine Arts in Copenhagen. During 1972–1981 Head of the Development Department, RECAU, the Regional Computing Centre at Århus University. During 1981–1996 Head of the Data Network Section and Head of the Network Infrastructure Strategy section at Jutland Telephone. During 1996–1999 Manager for Infrastructure Network Technology and Strategy at TDC, Tele Denmark. From 1999– onward Professor in Distributed real-time Systems and from 2004 as Head of NetSec, Networking and Security section, CNP, Head of Center for Network Planning and Co-director for CTIF, Center for TeleInFrastructur at Aalborg University. He has been project leader for a number of national and international R&D projects and acted in high level advisory tasks within the European Commission

on the R&D framework programmes in DGXIII and with United Nations UNDP activities. Present research is focused on Infrastructure Architecture and Modelling Tools for Network Analysis and Design.