# Upper Bound Performance Estimation for Copper Based Broadband Access

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# Upper Bound Performance Estimation for Copper Based Broadband Access

Michael Jensen and Jose M. Gutierrez

***Abstract*—Around 70% of all broadband connections in the European Union are carried over copper, and the scenario is unlikely to change in the next few years as carriers still believe in the profitability of their copper infrastructure. In this paper we show how to estimate the performance upper bound of copper based access connections at a household level by using Geographical Information System data. This can be combined with different configurations of DSLAMs distributions, in order to calculate the required number of active equipment points to guarantee certain QoS levels. This method can be used to define the limitations of copper based broadband access. A case study in a municipality in Denmark shows how the estimated network dimension to be able to provide video conference services to the majority of the population might be too high to be implemented in reality.**

***Keywords*—Network Planning, Broadband Access, DSL, Digital Divide.**

## I. Introduction

The predominant household's broadband access in Europe is still copper based. Around 100 million households are connected over the cooper infrastructure [1].

While the popularity wireless of technologies such as 3G or LTE is rapidly increasing in the mobile context, it is very unlikely that they will replace the fixed broadband connections for households or businesses. In general, wired connections perform better in sense of lower BER (Bit Error Rate), lower latency, or higher bandwidth among others [2].

In relation to wired networks, fiber based technologies are marginally penetrating in certain regions, but as an overall picture, copper will still dominate for the next 5-10 years. The transition of copper-fiber has been widely reported to be slowly performed [3], and copper and fiber will co-exits for some years [4]. Therefore, copper based technologies are and will be the most relevant in the market in the near future. Consequently, such infrastructure is still required to be modelled and characterized, in order to evaluate its capabilities according to current requirements and demands to offer new services [5].

One of the main constraints in transmissions over copper is the attenuation and degradation of signals [6]. This feature implies a limitation on the distance between customers and DSLAM cabinets. The longer this distance is, the lower the available bandwidth becomes for the users. Theoretically, the attenuation suffered by the signals is 13,81 dB/km, however in reality this value is higher [7].

Hence, it is possible to evaluate the performance capabilities of each household connection based on this distance at an individual level.

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We propose to evaluate the network using methods based on this distance, in order to provide an upper bound on the performance possibilities of each household or business broadband connection. Other factors may influence the performance of the copper based connections such as electromagnetic interferences (EMI) [8], but this work is focused on calculating the best possible case in order to define the infrastructure's limitations.

This type of evaluation is important, in order to know what new services can be delivered to whom, under what conditions, and who will not have that possibility. As ISPs usually advertise higher data rates that what they can actually provide [9], these are not a reliable source in this context.

This evaluation may provide information about networks upgrade needs in terms of cost or coverage, in order to facilitate the access to high demanding services to the customers that do not have that chance. In this way, the costs of narrowing the technological gap urban-rural (digital divide) can be estimated.

The main goal of this work is to present a method for estimating an upper bound of the capabilities of copper based access network at a household level. This upper bound calculation is based on a distributed location of DSLAMs, and the maximum possible DSL performance as a function of the distance DSLAM-household. In addition, the use of this method is illustrated in a simple case study in the municipality of Lolland in Denmark. The experiments show the infrastructure requirements, and dimension, for providing basic already existing services to the majority of the population in the studied region ($> 90$ %).

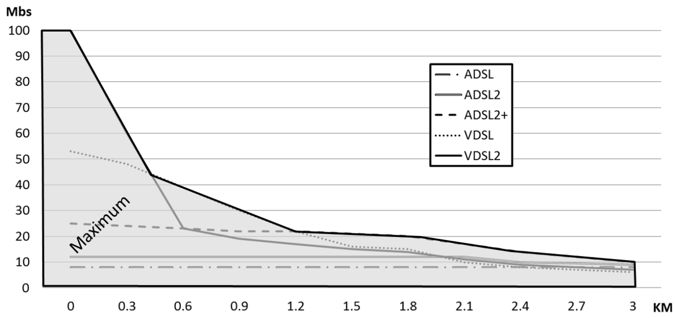
The rest of the document is organized as follows: Section II summarizes the background and important concepts behind this work's idea. Section III describes in detail the proposed methodology. Section IV presents the case study illustrating the application of the method. Finally, Section V shows the conclusion.

## II. Background

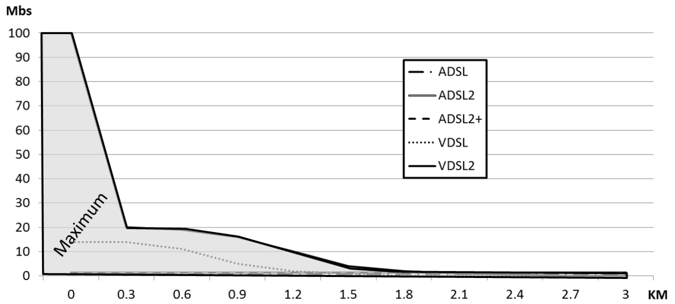
### *A. The copper infrastructure*

Traditionally, since the telegraph times, wired communications have been carried over copper infrastructures, including the last mile. Currently, copper based broadband access connects around 47% of the households in the EU-27 (67% have some sort of broadband access connection) [1].

Optical fiber technology can provide much higher data rates at much longer distances [10]. However, copper infrastructure is pushed to still produce revenue at the access level and initiatives are taken toward partially solving the distance vs.




(a) Downstream




(b) Upstream

Fig. 1. Data Rates Vs. Distance.

speed problem. Examples are the near future integration of Vectoring [11], Phantom , or G.Fast [12] technologies over the existing DSL equipment. Unfortunately, these technologies can be used in a very limited range from the DSLAM cabinet where users are already provided with decent internet connections (i.e. Vectoring is claimed to provide connections up to 100 Mbs in a 300m range).

The DSLAMs can be considered the connecting node between the fiber and the copper infrastructures. The active DSL equipment is installed in these cabinets. They collect all the cables connecting the households in the area, and the flowing information is converted electric from/to optic to be transported.

**Available data rates vs. distance**

One of the main constraints in data transmission over copper is signal attenuation and degradation influenced by the distance between the users and the active equipment. Fig. 1 presents the theoretical maximum up/downstream data rates of the most popular DSL technologies as a function of the distance to the DSLAM. The data is extracted from [13], among others.

These figures indicate that copper based access technologies are really promising in very short distances to the DSLAMs. However, for middle and long distances, problems may arise to support high bandwidth demanding applications. For example, for households 2 km away from a DSLAM, it would be impossible to enjoy 3D TV broadcasts, requiring a minimum of 18 Mbs downstream [14].

### B. Evaluation methods related work

The literature in relation to the evaluation of access connections is very diverse. Usually, this type of networks is evaluated in terms of performance, based on empirical data. Basically, these consist of measurements while sending and receiving data. Examples are among others: cable and DSL connections in the US are measured in terms of latency, jitter, or packet-loss rates in [15], or wireless access traffic is measured and the throughput is presented for different types of traffic in [16]. This kind of studies provide a performance analysis but do not really treat the potentials and limitations of the infrastructure itself.

In relation to the level of detail, usually this is done on county or zip code level. Some of the most recent examples are [17] and [18] where broadband availability is studied in different counties in order to illustrate the technological difference between urban and rural areas. It is rarely found in literature performance analysis at household level. Only very few studies go into this level of detail, for example the authors in [19] estimate the cost of three types of access technologies to provide high speed connections to most of the households in the state of Victoria, Australia. However, the work is very basic with no specific details about equipment placement, or traces followed by the lines are provided.

In connection with the measurement and evaluation of the distance between the DSLAMs and households, very few studies are found, probably due to the confidentiality of the data required to perform such analysis. The most relevant work is [5], where a study of the broadband possibilities in a county in Ohio is conducted estimating the Euclidean distance DSLAM-household. Then, an optimization experiment is performed in order to provide a better coverage by properly placing the DSLAMs. The work is done at a household level, but no cable traces are used for the evaluation or the experiments.

## III. Methodology

The methodology described below is based on available GIS data of the households and roads in the evaluation area. In an ideal scenario, the information regarding the exact location of the DSLAMs, and the traces followed by the cooper cables would be available. But this information is usually confidential, and it cannot be disclosed to third parties or used publicly. The following assumptions are taken, in order to solve the lack of these two important pieces in the puzzle:

- DSLAMs location: Various scenarios are tested varying the number of DSLAMs and their location according to the method described below.
- Traces followed by the copper lines: It is assumed that lines are installed by the roads or streets. Each household is assumed to be connected to the nearest DSLAM. A shortest path algorithm is used, in order to make the distance calculation DSLAM-household.

### A. DSLAMs location

The intention of the experiments is to distribute the DSLAMs as equally as possible across the studied area, so

TABLE I
SERVICES AND REQUIREMENTS.

| Service | Downstream | Upstream | Dist. Limitation |
|---|---|---|---|
| **3D TV** | 18 Mbs | 0 | 1,8 km |
| **Youtube HD 1080P** | 8 Mbs | 0 | 3 km |
| **E-Health Video** | 5 Mbs | 5 Mbs | 1.2 km |
| **HD Skype** | 1.5 Mbs | 1.5 Mbs | 2 km |

TABLE II
NUMBER OF DSLAMS BY CASE.

| **Cell Dim. / MHC** | **0** | **10** | **20** | **30** |
|---|---|---|---|---|
| **1000** | 840 | 396 | 226 | 150 |
| **2000** | 242 | 217 | 188 | 158 |
| **3000** | 120 | 112 | 108 | 105 |
| **4000** | 72 | 69 | 66 | 66 |
| **5000** | 50 | 48 | 46 | 46 |

it reflects an upper bound situation. In reality, the DSLAMs would usually be more concentrated in highly populated areas. The area under study is divided into square cells and each cell is assigned a DSLAM. Then, the center of gravity based on the household geographical information in each of the cells is calculated as presented in Eq. 1. $n_j$ being the number of nodes in each cell $j$, and $x_i$ and $y_j$ the coordinates of each household. The DSLAMs are placed at the closest road segment point to the center of gravity of each cell.

$$DSLAM_j = \left( \frac{\sum x_i}{n_j}, \frac{\sum y_i}{n_j} \right) \forall i \in cell\ j\ . \qquad (1)$$

Different experiments are carried out varying the dimensions of the cells as 1000, 2000, 3000, 4000, and 5000 meters. The decision for each cell to have its own DSLAM is based on *Minimum Household per Cell,* $MHC$. A DSLAM is placed on a cell if the number of household within it is higher than $MHC$. In the case study, the given values for $MHC$ are: 0,10, 20, and 30.

### *B. Distance DSLAM-Household*

As mentioned above, the distance followed by the lines is calculated using the road distance between each household and its corresponding DSLAM. GIS data about all the roads in the area is available, and based on this, the shortest distance is calculated. The calculations are performed by connecting each household to the nearest DSLAM regardless of the cells they belong to. This is not always the case in real networks, and again, this method will give slightly shorter than in reality for few specific households in order to provide a performance upper bound. It is assumed that there is no limitation on the number of households that can be connected to one DSLAM.

### *C. Services*

In order to provide a more practical overview of the analysis, the results are provided in the context of available services for each household.

The evaluated services and their characteristics are presented in Table I and taken from [14], [20], [21], and [22]. The characteristics include the up/downstream requirements and, based on these the maximum DSLAM-household distance to be able to properly deliver the service. The restrictions for video conference services come due to upstream limitations.

## IV. CASE STUDY

The case study consists of estimating the upper bound of the copper access connections in the municipality of Lolland, Denmark. The area covered is 889 km$^2$ and the total number of household evaluated is around 30.000. The DSLAMs are distributed accordingly to the described methodology in Section III, and Table II presents the resulting number as a function of the cells' dimensions and $MHC$. As a reference point, a municipality of these characteristics will have between 50-100 DSLAMS. Thus, the distribution presented for 4000-5000 m cell dimensions would be the closest to reality.

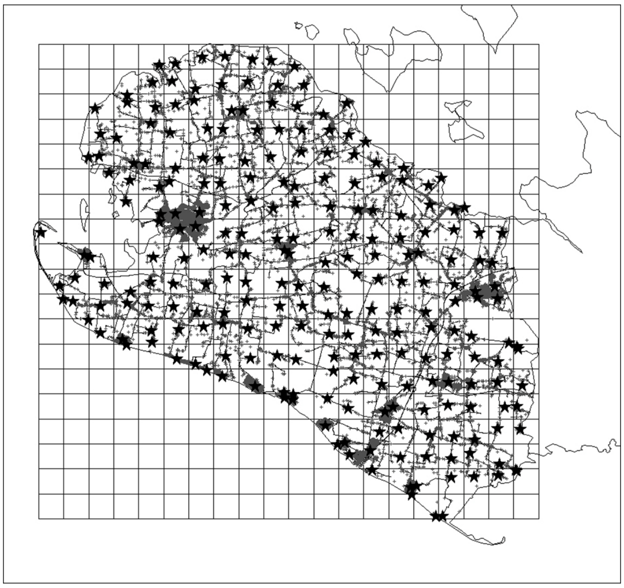


Fig. 2. Lolland Municipality Cell Division, 2000 m.

Fig. 2 depicts, as an example, the studied region and one of the cell division cases (dimension=2000 m and $MHC = 0$), the stars represent the calculated location of the DSLAMs. Based on these DSLAMs distributions, Fig. 3 presents the percentage of households that would have access to the studied services in relation to the number of DSLAMs installed.

The results depict a significant difference between the type of studied services. While offering HD Youtube to the majority of the population is possible with a reasonable number of DSLAMS (between 50-100), the other services require a significant number of additional DSLAMs to go above 90% of coverage. In that case, the number of required DSLAMs is in the order of 400. In addition, to offer full coverage for all the services will imply to install 800 DSLAMs.

This results arise some interesting questions still to be answered in relation to the coverage boundaries of DSL technologies. Conditioning factors such as deployment costs, energy utilization, or operational costs including maintenance of the equipment need to be further investigated, in order to

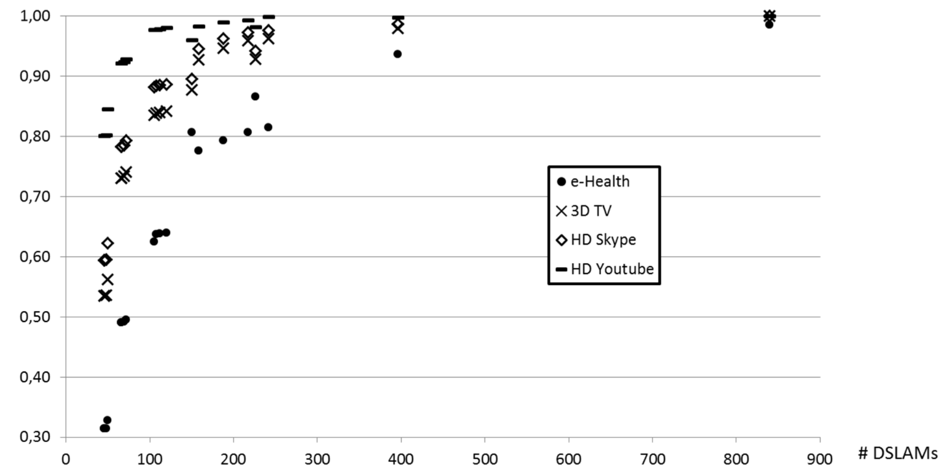



Fig. 3. Percentage of Households Covered per Service vs. Number of DSLAMs.

define the limitations of DSL technology in relation to its infrastructure.

## V. Conclusion

This work presents a methodology, in order to evaluate the upper bound performance of cooper based access infrastructure. This methodology considers one of the main factors affecting the performance of DSL connections, the distance between the active equipment and end users. In addition, this upper bound is based on a distributed location of the DSLAMs. In this way, the complete evaluated areas can be covered, rather than focusing on highly profitable/populated neighbourhoods.

A basic case study is presented, covering the Danish municipally of Lolland. The purpose is to illustrate the copper infrastructure capability of providing different services to the end users. Results show that an unrealistic number of DSLAMs would be required in order to provide video conference services to the majority of the population ($> 90$ %). In addition, it has been identified that one of the main reasons for this unrealistic requirements is lack of sufficient upstream bandwidth in DSL connections.

The development of new technologies such as Vectoring or Phantom, will unlikely solve the problem. These will provide good performance in very short distance but will not have any influence on the users that are lacking proper access to broadband, due to their geographical location in rural areas.

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