Milan Meninger

Synthesis of HFTP Multilayer Cell Access Network

This paper describes the multilayer cell architecture of hybrid-fibre twisted-pair (HFTP) access network offering optimised design for both narrowband and broadband services, simultaneously. The method described is suitable for network conceptual considerations and is demonstrated on five examples of networks offering services from the analogue plain old telephone service (POTS) up to broadband services supported by digital very-high-speed digital subscriber line (VDSL) technology up to 52 Mbit/s.

Introduction

The recent development era of telecommunications is characterised by great efforts to better utilise existing telephone symmetrical user lines, currently estimated at 700 million installed across the world.

High-frequency spectrum components have greater attenuation and are more exposed to cross-talk interference than lower frequency components. This phenomenon reduces the maximum length of access digital sections operated at higher bit rates.

The range of a broadband (BB) digital access section can be up to ten times shorter than a POTS access section. In other words, the range of BB user lines is approximately only one order of magnitude greater than are dimensions of urban elements (that is houses, roads etc.) compared with the POTS range that is two orders greater. Narrowband (NB) access equipment is usually located in the centre of gravity of its *user area* to minimise the cost of user lines. BB access digital sections are relatively very short and BB access equipment is likely to be distributed geographically homogeneously across the network, independent of the user density.

Investment and operational expenses of BB access network increase with the bit rate used. As not all the users will require the highest offered bit rate the access network will be decomposed into layers consisting of access cells of different dimensions for different bit rates. The mutual relationship between these cells must also be optimised to reach efficient economical parameters for the whole network.

Definition of Multilayer Access Cell Network Architecture

Model of multilayer network is based on four following architectural elements.

Access Cells (AC) form the elementary architectural elements of access network (AN) and cover the area from which all users of the same service are connected to a common access equipment belonging to a specific technology class. Each AC is characterised by the location of its central access equipment, called the *cell centre* ($CC_j^{(i)}$) and the cell territory ($T_C^{(i)}$), where the upper index i denotes specific technology class and the bottom index j specifies the ordinal number of the AC.

Access Layer (AL) represents the architectural element one level higher than AC and consists of the association of ACs of the same class (Equation 1).

$$AL^{(i)} = \bigcup_{\forall j} AC_j^{(i)}$$

AL is characterised by the set of relevant cell centres ($CC_j^{(i)}$) and the association of relevant AC territories $\bigcup T_{Cj}^{(i)}$

As an AL is composed of ACs, so the access network is composed of NL access layers, equipped with NL significantly different technologies, and the feeder layer (FL), providing interconnections of CCs to the Network Centre (Equation 2).

$$AN = \bigcup_{i=1}^{NL} AL^{(i)} \bigcup FL$$

Network Centre (NC) represents the geographical association of service node interfaces (SNIs) and completes the description of the whole network model.

Reliable operation of the network requires all the geographical distances, denoted *GD{.}*, between users located at internal cell points and the corresponding CC to comply with the following relationship (Equation 3),

$$GD\left\{CC_j^{(i)}; r_j^{(i)}\right\} \leq \rho^{(i)}$$

where $\rho^{(i)}$ denotes the range of user lines equipped with i class technology.

The described network model is shown in Figure 1.

Optimisation of Multilayer Cell AN Architecture

Optimisation of AN from the *Life Cycle Cost* view can be modelled by the following relationship (Equation 4),

$$\int_{LC} \frac{B(t)}{M(t) + I_M(t) + E(t) + I_E(t) + O(t)} dt \ldots \max$$

where *B(t)* represents time course of revenues from provided services and components in the denominator which denote costs of transmission media and their installation, costs of access equipment and their installation and network operation and maintenance costs, respectively.

Milan Meninger:
SPT Telecom, a.s.
E-mail: milan.meninger@spt.cz

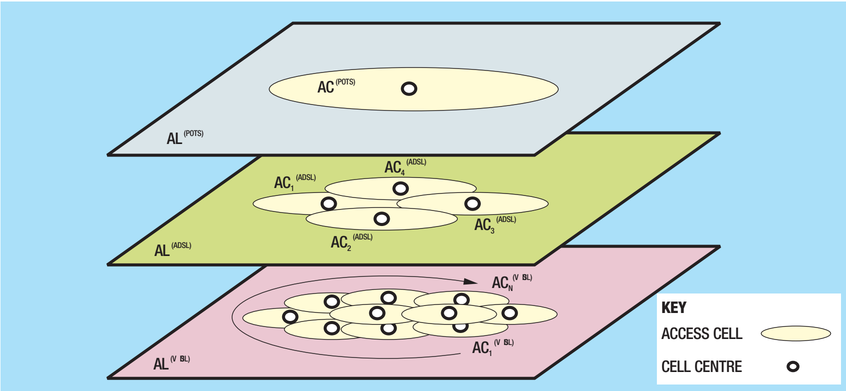


Figure 1—Example of geographical decomposition of the access network into POTS, ADSL and VDSL access layers and the relevant access cells

Practical experience indicates that operational and maintenance expenses have small correlation with specific classes of transmission media and technology. Therefore, on this level of abstraction, the *O(t)* factor can be neglected in next considerations. Finally, the rest of the denominator of Equation 4 can be decomposed into two separate parts, the first dealing with equipment aspects and the second dealing with transmission media aspects of the network model.

Equipment aspects

General experience shows that the asymptotic cost of technically matured telecommunication hardware is mainly determined by its physical volume which results in the following simplified condition for minimisation of the network summarised equipment cost (Equation 5),

$$NEL\left\{\bigcup_{i=1}^{NL}\bigcup_{\forall j}\left\{CC_j^{(i)}\right\}\right\} \ldots\text{. min}$$

where the function *NEL{.}* denotes the number of entries of its set argument.

Physical realisation of Equation 5 can be interpreted as the association of CCs belonging to different layers but located in the same geographical location combined in one common multilayer CC. In technological terms, the association of CCs represents multiplexing of bearer channels into one aggregated stream.

Media aspects

The primary objective of HFTP access network architecture is an upgrade of existing copper POTS access network for future BB services. Therefore, the following considerations dealing with transmission media and their installation can be limited only on the optical FL.

The general rule says that the cost of a cable installation is higher than the cost of the cable itself, therefore the cost of cable infrastructure can be roughly approximated by the length of cable routes. The minimum cost of the FL infrastructure is given by the condition (Equation 6),

$$\sum_{T_{AN}}\bigcup_{i=1}^{NL}\bigcup_{\forall j} GD\left\{CC_j^{(i)}; NC\right\} \ldots \text{min}$$

There are two main phenomena influencing coverage efficiency of a multilayer cell AN territory with ACs.

Cell overlapping

As stated above, the theoretical operational area of an access equipment is the shape of a circle, but full network territory coverage by ACs results in the overlapping of the outer parts of adjacent ACs. The coverage efficiency can be expressed by the *cell overlapping factor* (Equation 7).

$$\eta_C^{(i)} = \frac{T_C^{(i)}}{\pi\rho^{(i)2}}$$

where $T_C^{(i)}$ denotes the net operational non-overlapping territory.

In spite of the best efficiency for hexagon cell shape, square cell shape was selected for further modelling due to its identical parameters in orthogonal directions.

Layer overlapping

The problem of ACs overlapping is even more critical in a multilayer AN where different ALs can differ in an order. This phenomenon can be quantified by the *layer overlapping factor* (Equation 8)

$$\eta_L^{(i)} = \frac{T_L^{(i)}}{\sum_{j \ni AL^{(i)}} T_{Cj}^{(i)}}$$

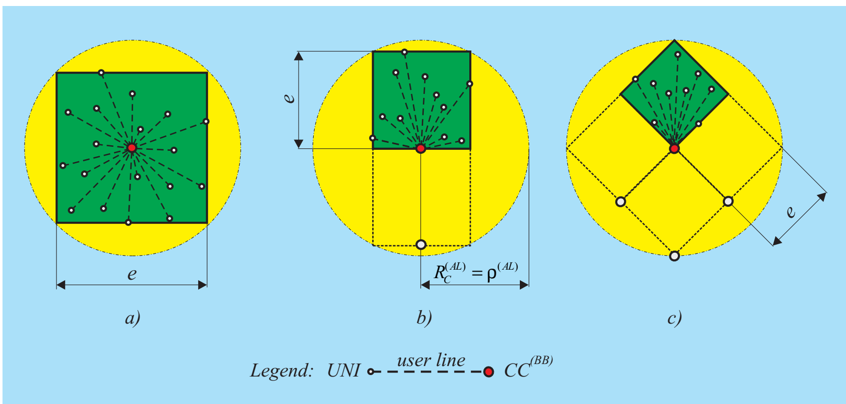
Overlay Broadband Infrastructure

Old cable networks were originally designed optimally for POTS applications with radial tree topology and later selection of places for CCs in order to enable injection of BB signals into POTS user lines will not be always simple. Figure 2 demonstrates how the position of CC in AC influences the total AC territory, despite the range staying identical in all cases. To increase probability for finding a realisable solution, the worst case of CC position in its AC will be used in the following considerations; that is, in a corner of the AC.

For the modelling of FL topology a segment decomposition approach is adopted. According to this method the territory around NC is decomposes into four 'V' segments in which the same topological paradigm is repeated, see Figure 3. (Note: The number of segments used is not unique, but the impact of the number of segments on AN infrastructure parameters is not analysed in more detail here.)

Quantitatively, the network cable infrastructure occupying *k* levels of ACs can be described by the total

Figure 2—The impact of CC position AC dimensions



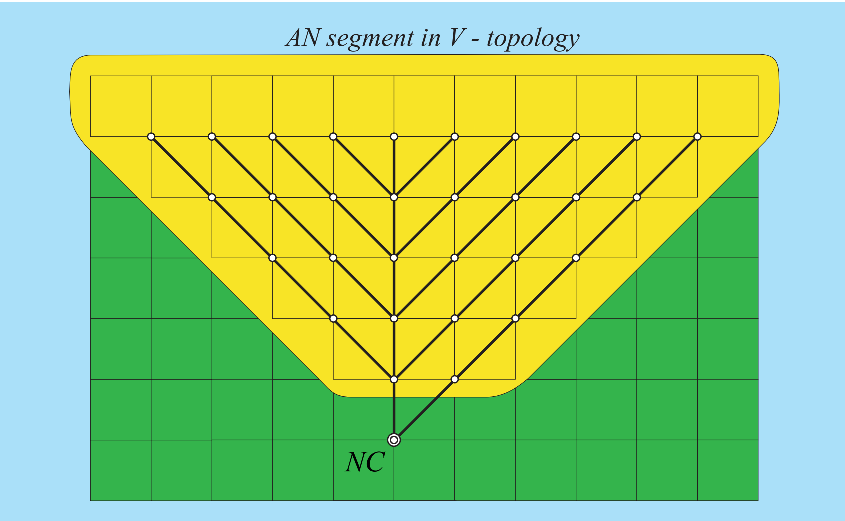


Figure 3—Paradigm of overlay V-topology

length of cable trenches (LT_{V_k}) and by the total territory (T_{V_k}), defined by Equations 9a and 9b.

$$LT_{V_k} = 4(k-1)\left[(k-1)\sqrt{2}+1\right] e$$

$$T_{V_k} = 4k^2e^2$$

where e denotes the length of the AC edge.

Synthesis of Overlay Network

So far, the majority of AN matters have been solved only from the viewpoint of one isolated network layer. The design of the multilayer cell access network is solved in the following four steps:

1 *Arrangement of the set of involved technological classes* All NL involved access technologies are arranged in the descending order according to their ranges; that is, $\rho^{(NL)}$ corresponds to the shortest one.

2 *Calculation of relative ranges* All ranges are converted into relative form related to the shortest one (Equation 10),

$$\rho_R^{(i)} = \frac{\rho^{(i)}}{\rho^{(NL)}}$$

From this step it follows that the range is $\rho_R^{(NL)} = 1$.

3 *Calculation of transformed ranges* Relative ranges $\rho_R^{(i)}$ are transformed into integer $\rho_T^{(i)}$ values. This step supports collocation of some CCs of different ALs and this way also supports fulfilling requirements of Equation 5. The shortest range of applied technologies becomes the basic module AM of the FL web. To guarantee necessary transmission parameters of all ALs it is ‘useful’ to select all the transformed ranges $\rho_T^{(i)}$ shorter than their parent relative ones (Equation 11).

$$\rho_T^{(i)} \le \rho_R^{(i)}$$

The term ‘useful’ is used for the reason that some exceptions of this rule are tolerable to the extent of the ‘geographical range margin’ (see Note under Table 1).

4 *Correction of Layer overlapping* So far, design of individual ALs was independent, and therefore individual total layer territories can exceed the basic $T_C^{(POTS)}$ territory by $MS^{(i)}$ AM modules (Equation 12)

$$MS^{(i)}AM = M^{(i)}\rho_T^{(i)} - M^{(NL)}\rho_T^{(NL)}$$

where $M^{(X)}$ denotes the number of applied $AC^{(X)}$ levels.

The $MS^{(i)}$ parameter determines a zone of $AC^{(i)}$s which shall be shrinked toward the NC. The shrinking zone may be distributed between up to $MS^{(i)}$ cell levels to increase their signal to noise margin. As the last step, the Layer overlapping factor can be derived from equation 8. (Equation 13.)

$$\eta_{LV}^{(i)} = \frac{8\left(\dfrac{e^{(POTS)}}{\rho_G^{(i)}}\right)^2}{\left[\sqrt{NEL\left\{CC_V^{(i)}\right\}}+1\right]^2}$$

Application of the Method on existing xDSL technologies

Derived method will be demonstrated on existing xDSL technologies, parameters of which are summarised in Table 1.

Results of analyses of ANs supporting different maximum bit rates are summarised in Table 2, Table 3 and Figure 4. Brief figures gathered in Table 2 and Table 3, are completed by Figure 5 which converts the light grey columns in the tables into an idealised network plan of AN infrastructure supporting the maximum bit rate of 26 Mbit/s. The collocation of CCs of different network layers can be seen in Figure 5. Notice the merging of $CC^{(3)}$s and $CC^{(4)}$s.

Table 1 Ranges of existing digital access technology classes on 0·4 mm copper pairs

AL reference code	Access Technology	Maximum bit rate downstream /upstream (Mbit/s)	Theoretical range (km)	Geographical range (km)
$AL^{(1)}$	BA ISDN/ POTS	0,16/0,16	$\rho_H^{(1)} = 4{\cdot}3$	$\rho_G^{(1)} = 3{\cdot}04$
$AL^{(2)}$	ADSL	6/0,6	$\rho_H^{(2)} = 2{\cdot}8$	$\rho_G^{(1)} = 2{\cdot}00$
$AL^{(3)}$	$VDSL^{(13Mb)}$	13/1,6	$\rho_H^{(3)} = 1{\cdot}5$	$\rho_G^{(1)} = 1{\cdot}06$
$AL^{(4)}$	$VDSL^{(26Mb)}$	26/3,2	$\rho_H^{(4)} = 1{\cdot}0$	$\rho_G^{(1)} = 0{\cdot}71$
$AL^{(5)}$	$VDSL^{(52Mb)}$	52/6,4 or 13/13	$\rho_H^{(5)} = 0{\cdot}3$	$\rho_G^{(1)} = 0{\cdot}21$

Note: In Table 1 are specified theoretical and geographical ranges. The latter one represents 0·707 shortening of user lines due to rectangular bends, a margin for multisystem interference and other degradation factors.

Table 2 AC dimensions for different combinations of services

Access Layer	Cell Edge (km)			
$AL^{(1)}$	2·23	2·50	2·25	2·15
$AL^{(2)}$	1·34	1·50	1·50	1·07
$AL^{(3)}$	0·74	0·50	0·75	-
$AL^{(4)}$	0·45	0·50	-	-
$AL^{(5)}$	0·15	-	-	-

Table 3 Layer overlapping factor for different network layers

Access Layer	Layer overlapping factor (-)			
AL(1)	1·071	1·352	1·096	1·000
AL(2)	0·619	0·781	0·663	0·578
AL(3)	0·979	0·445	1·000	
AL(4)	0·786	1·000		
AL(5)	1·000			

Conclusion

The method described in this paper is not for precise network planning but rather for conceptual modelling of access network infrastructure determined for xDSL technology supporting different bit rates. The method can help in estimation of network complexity and evaluating range compatibility and utilisation of planned technologies.

For many operators, ADSL technology seems to be a good starting phase for BB AN construction. Using the described method, two interesting and practical results were obtained.

Doubling the density of feeder cables and ONUs in network originally designed for ADSL technology might in future increase the maximum supported bit rate up to 13–26 Mbit/s, depending on the original cell size.

On the other hand, the modelling showed that reconstruction of AN for the maximum bit rate 52 Mbit/s would require reduction of the original ADSL cell dimensions by factor of nearly 10.

Biography

Milan Meninger
SPT Telecom, a.s.

Milan Meninger graduated on the Czech Technical University in Prague in 1968 and at the same university obtained his scientific degree C.Sc. (similar to a Ph.D.) in 1979. From 1968 to 1979 he worked in the research and development laboratory of Tesla, the Czech telecommunication manufacturer, where he dealt with design of digital lines. Between 1979 and 1995, he was working at the state PTT research and development centre. Since 1995, he has worked for SPT Telecom, a.s., the major Czech telecommunication operator, where he is responsible for specification and selection of access technology. He is also active in STC TM6 of ETSI. Milan is also the author of 14 patents and many technical papers.

Figure 4—Density of feeder cables and ONUs in broadband HFTP Access Network

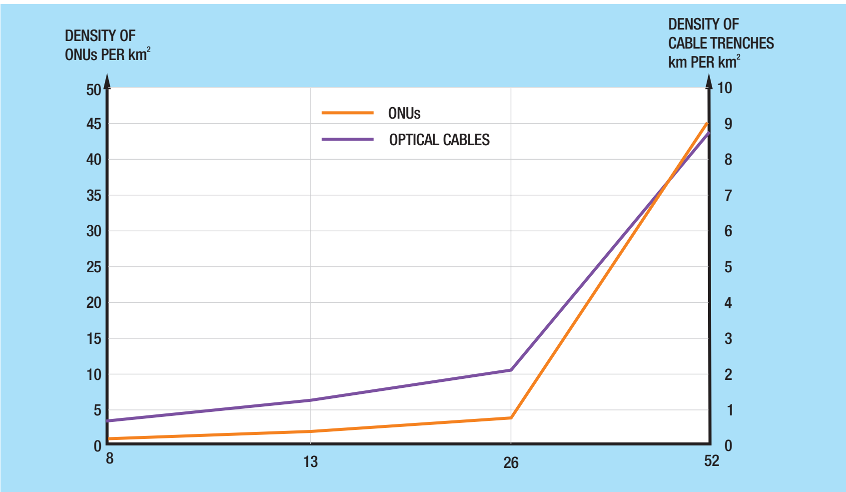


Figure 5—Idealised plan of four layer AN