Rafał KRÓLIKOWSKI

Politechnika Wrocławska, Instytut Telekomunikacji, Teleinformatyki i Akustyki

HFC network return path data capacity

***Abstract**. In this paper we discuss HFC cable TV return path analytical model, which allows for calculation of data capacity. Return path transmissions are carried out using multiple M-QAM carriers. Based on the suggested analytical model we calculate maximum theoretical and then practical information capacity of the return path depending on the spatial density of subscribers in the considered coaxial network segment. (**Pojemność informacyjna kanału zwrotnego w sieciach HFC**).*

***Streszczenie.** W artykule przedstawiono rozważania na temat pojemności informacyjnej toru zwrotnego sieci telewizji kablowej budowanej w technologii hybrydowej HFC. Transmisja w torze zwrotnym odbywa się z wieloma podnośnymi M-QAM. Na podstawie zaproponowanego modelu analitycznego obliczono maksymalną teoretyczną, a następnie praktyczną pojemność informacyjną toru zwrotnego w zależności od gęstości przestrzennej abonentów w rozpatrywanym segmencie sieci współosiowej.*

Keywords: hybrid CATV networks, return path transmission, information capacity
Słowa kluczowe: hybrydowe sieci TVK, transmisja w torze zwrotnym, pojemność informacyjna

Introduction

In this paper in reference to our earlier publication [1] we present the results of the HFC network simulations based on the proposed in [1] model of the return path. The main aim of this work is to demonstrate that the information capacity of the return path depends of the spatial distribution of subscribers.

To remind the background, cable TV systems apply HFC (*Hybrid Fiber Coax)* (fig.1) technology, where the coaxial network segments have a hierarchical (tree) topology and where the coax subscriber links branch out from the *ONU* (*Optical Network Unit*) nodes. As for ONU nodes, these are connected through a star optical network to the network's headend. Besides standard broadcast TV and radio, cable TV networks also provide an increasing number of various two-way services using the return path (uplink), such as: high speed Internet access, e-mail, voice over IP, video telephony or video on demand. Return path transmissions are carried out using multiple M-QAM carriers in the band from 5 to 65 MHz.

Considering the increasing use of return path digital transmissions it is important to be able to model the return path and relate its data capacity to the network topology. One of the main problems when designing new HFC cable TV networks or planning modernization of old ones is to properly size the coax network segment for each ONU node. Deep network segmentation, i.e. major reduction of subscriber sockets per each optical node, for example 100 per node, obviously would be advantageous to the subscriber in regards to the available bandwidth but also increases the cost of network upgrade.

However, the costs arising from the need to expand the optical network as well as the maintenance/functional aspects, such as for example the much more difficult fiber optic workmanship compared to coax, seem to justify having a larger coaxial network segment. This is especially true for existing cable TV networks, where one would prefer to maintain as much as possible of the existing network infrastructure. Therefore it is important to know what are the limits of the return path data capacity and what it depends on.

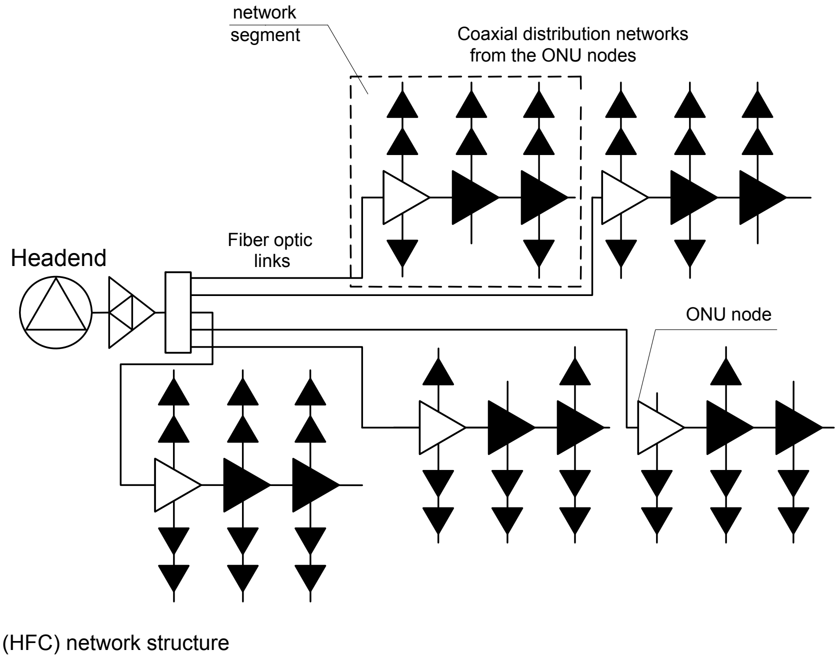

Fig. 1 Hybrid Fiber Coax (HFC) network structure

Capacity calculation

Assuming independence of the optical and coax network noise and interference sources, we can define the total incidental carrier to noise and interference ratio in the return path $CINR_{TZ}$ based on the relation:

$$CINR_{TZ} = -10\log\left(10^{-\left(\frac{CINR_{ONU}}{10}\right)} + 10^{-\left(\frac{CINR_{LINK}}{10}\right)}\right), \tag{1}$$

Where: $CINR_{ONU}$ is the carrier to noise and interference ratio at the input of the return path optical transmitter, $CINR_{LINK}$ is the carrier to noise and interference ratio of the optical link.

$CINR_{ONU}$ *and* $CINR_{ONU}$ can be calculated using relations given in [1].

Assuming a band $B_{tz,}$ the potential capacity C_{max} of the return path can be calculated using the Shannon theorem:

$$C_{\max} = \int_{B_{tz}} \log_2\left(1+10^{\frac{CINR_{TZ}(f)}{10}}\right)df \quad . \tag{2}$$

For typical return path parameters it is possible to define the maximum capacity C_{max} of the B_{tz} = 60 MHz return path bandwidth, as function of the number of subscriber sockets *N* for the given ONU, full usage of the return band (for example, by 18 frequency channels – each with B_{kz} = 3,2MHz) and for a network covering different density urban areas. The calculations take into account non-linear distortion introduced by the distribution network and assume the following, typical parameters of the optical path:

$P_{o,d}$= -8dB, m_{rms} = 0,05, *RIN= -145dB/Hz*, r_d*= 0,85 A/W*. I_r = $7\, pA/\sqrt{Hz}$. They also take into account cross channel interference. The results of simulations of the maximum capacity are shown in figure 1.

We can determine the actual capacity of the return path C_{tz} if we know the modulation type, its spectral efficiency e_B and the number of transmitted return channels l_{kz}. The maximum number of return channels depends on the total return bandwidth B_{tz} and bandwidth of the individual return frequency channels B_{kz} , which depends on the modulation speed s_r. It should be noted, that for a given modulation type we can assess the maximum number of subscriber sockets per an ONU, at which the error rate for a system without error correction shall not exceed *BER* > 10^{-9}.

The total actual throughput for the return path can be calculated using the formula:

$$C_{tz} = \sum_{i=1}^{l_{kz}} e_{B\,i} s_{r_i} \ . \tag{3}$$

Assuming identical return channels (i.e. having the same bandwidth) and same modulation of all RF carriers, we can simplify the formula (3) to:

$$C_{tz} = l_{kz} e_B s_r = INT\left(\frac{B_{tz}}{B_{kz}}\right) e_B s_r \ . \tag{4}$$

Table 1 presents example calculated return path throughputs for different digital modulation types, different bandwidths of return channels and different number of frequency channels (filling the full return bandwidth). We have determined:

1) the maximum number of subscriber sockets per the single ONU – i.e. the maximum coaxial network segment size for a given modulation type and areas of different urban density,

2) potential return path throughput depending on the urban density, for a typical predefined number (*N* = 500) of subscriber sockets per the single ONU,

3) gross bit rate per single subscriber, depending on the urban density of the installed network.

Table 1 Return path throughput depending on the applied digital modulation type

Parameter	**Value**			
Modulation type	QPSK	16-QAM	64-QAM	256-QAM
Required minimum carrier to cumulative noise and interference of the return link $CINR_{TZ\_MIN}$ *[dB] for BER<*10^{-9}	16	23,1	29,3	35,4
Bandwidth of the single return frequency channel B_{kz} [MHz]	3,2	3,2	3,2	3,2
Maximum number of return frequency channels	18	18	18	18
Maximum number of subscriber sockets per ONU for dense urban areas	4765	2440	1045	338
Maximum number of subscriber sockets per ONU for average density urban areas	3150	1615	690	223
Maximum number of subscriber sockets per ONU for low density urban areas	1550	790	337	107
Spectral efficiency [b/Hz]	2	4	6	8
Gross bit rate [Mb/s]	92,16	184,32	276,48	368,64
Potential bit rate of the return path [Mb/s] for *N*=500 for a network in a highly urban area [Mb/s]	667 (1,34/socket)	667 (1,34/socket)	667 (1,34/socket)	667 (1,34/socket)
Potential bit rate of the return path [Mb/s] for *N*=500 for a network in an average urban area [Mb/s]	622 (1,24/socket)	622 (1,24/socket)	622 (1,24/socket)	622 (1,24/socket)
Potential bit rate of the return path [Mb/s] for *N*=500 for a network in a low urban area [Mb/s]	532 (1,06/socket)	532 (1,06/socket)	532 (1,06/socket)	532 (1,06/socket)
Gross bit rate per subscriber (data service saturation of 30%) for a network in a highly urban area and the max number of sockets served by the ONU zone [Mb/s]	0,065	0,252	0,882	3,636
Gross bit rate per subscriber (data service saturation of 30%) for a network in an average urban area and the max number of sockets served by the ONU zone [Mb/s]	0,098	0,380	1,336	5,510
Gross bit rate per subscriber (data service saturation of 30%) for a network in a low urban area and the max number of sockets served by the ONU zone [Mb/s]	0,198	0,778	2,73	11,48

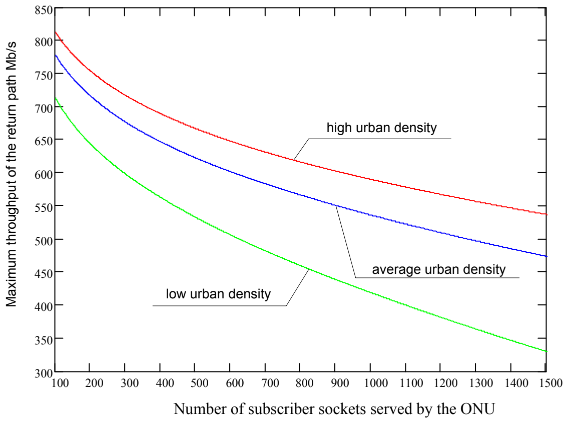

Fig. 2 Potential maximum return path throughput in relation to the number of subscriber sockets served by the ONU and different urban densities covered by the coaxial network

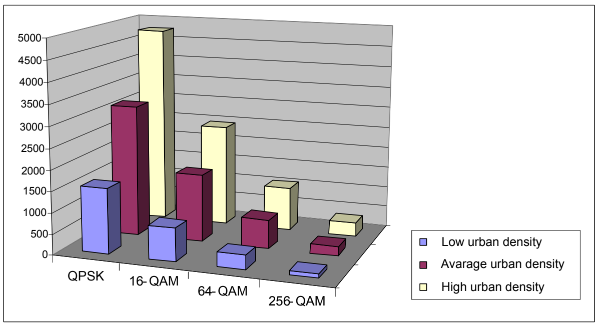

Fig. 3. Maximum number of subscriber sockets in a coaxial network segment, depending on the modulation type and urban density at the area covered by the HFC CATV network.

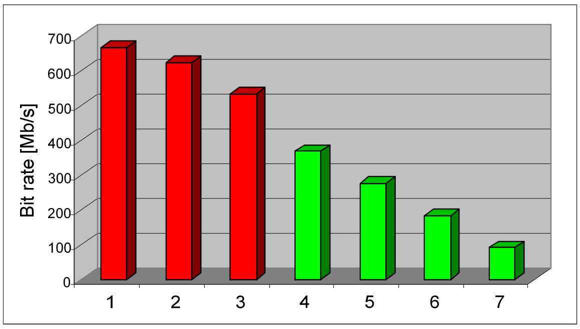

Fig. 4. Potential (red) and actual (green) bit rate of a single return path of a HFC network, for the following conditions: N=500 and the coaxial network located in an area of large urban density, N=500 and the coaxial network located in an area of average urban density, N=500 and the coaxial network located in an area of low urban density, Return path with channels using 256-QAM, Return path with channels using 64-QAM, Return path with channels using 16-QAM, Return path with channels using QPSK.

Analysis of table 1 and plots in fig. 2,3 and 4 leads to the following observations:

1) The increase of QAM valence leads to the increase of the requirements for carrier to noise and interference ratio for a given return path transmission channel. I.e. this also means that for predefined HFC network parameters and subscriber distribution (urban density) the number of subscriber sockets per given ONU / optical link decreases,

2) The potential return path throughput for a given number of subscriber sockets (served by a single ONU) will be the highest for a highly urban area. This relates mainly to small variation of network attenuation parameters, which in term relates to the smaller distances served by the coaxial distribution and building networks, larger number of sockets per each building amplifier and the total lower number of trunk-line amplifiers,

3) The actual capacity of the return path depends on the applied digital modulation type. Higher QAM allows for an increase of the bit rate, whilst having the same modulation speed and number of return frequency channels. However, with the increase of the number of return path signals, it is necessary to appropriately segment the coaxial network, so that the carrier to noise and interference ratio is sufficient to maintain the minimum BER requirements. The required segmentation will be the highest for areas of low urban density. This is caused by large variations in attenuation in the distribution and building networks and the relatively small number of subscriber sockets per each building or trunk line amplifier.

Summary

The paper considered together with our earlier work [1] presents a method for calculation of the HFC cable TV network return path data capacity. It shows that it is possible to relate the network topology to carrier to noise and interference ratio, and thus calculate the potential and actual throughput of the return path. The presented return path model allows for assessment of the foreseen per subscriber bit rate, depending on the number of subscribers served by the given ONU, subscriber distribution (urban density) and parameters of the network components.

Subdivision of the coaxial part of the HFC network into more segments, each serving a lower number of subscriber sockets, is necessary for high bandwidth interactive services. The importance of return path transmissions for two-way communications is vital to the proper assessment of system operation quality. In order to be able to increase the downlink throughput, we can add additional data transmission channels above the TV channel band. When it comes to the return path, we must manage with a relatively narrow transmission band, between 5 MHz to 65 MHz, and to make matters worse, which is also limited by diplex filters and affected by pulse interferences. Here, an increase of throughput can be achieved only by using higher QAM modulation, but this requires better carrier to noise and interference ratio. As we can see, it is necessary to size the coaxial network segment for a given ONU according to the return path modulation. The number of subscriber sockets served by a given ONU will also depend on the network topology, which depends on the subscriber distribution (urban density).

REFERENCES

[1] Królikowski R., HFC network return path performance modeling, *Przegląd Elektrotechniczny*, 87 (2011), nr 8, 248-252

[2] Królikowski R., Analiza wpływu parametrów i topologii sieci telewizji kablowej na pojemność informacyjną toru zwrotnego, *Rozprawa Doktorska*, Instytut Telekomunikacji i Akustyki, Politechnika Wrocławska, Kwiecień 2006

[3] Ciciora W., Farmer J., Large D., Adams M., Modern Cable Television Technology, *Morgan Kaufmann Publishers* 2004

[4] Bonang Ch., Bringing Home Bandwidth: Optimal HFC Access Architectures for New Builds, *Harmonic Inc. White Paper* www.harmonicinc.com, 2004

[5] Cox Ch. H., Analog Optical Links Theory and Practice, *Cambridge University Press,* 2004

[6] Królikowski R., Analiza łącza optycznego z bezpośrednią modulacją intensywności światła w systemach TVK, *Krajowa Konferencja Radiokomunikacji, Radiofonii i Telewizji KKRRiT 2005*, 15-17 Czerwca 2005, Kraków

Autor: dr inż. Rafał Królikowski, Politechnika Wrocławska, Instytut Telekomunikacji, Teleinformatyki i Akustyki, ul.Janiszewskiego 7/9, 50-372 Wrocław, E-mail: rafal.krolikowski@pwr.wroc.pl.