The Research of Increase of Channel Efficiency for IP Traffic Transmission over Digital Power Line Carrier Channels

Anton Merkulov, Viatcheslav Shuvalov
Siberian State University of Telecommunications and Informatic Sciences –
Faculty of Automatic Electrocommunication
Kyrova Str. 86, 630102 Novosibirsk, Russia
E-mail: anton-merkulov@list.ru, shwp@sibsutis.ru

***Abstract*—This article is devoted to the research of channel efficiency for IP-traffic transmission over Digital Power Line Carrier channels. The application of serial WAN connections and header compression as methods to increase channel efficiency is considered. According to the results of the research an effective solution for network traffic transmission in DPLC networks was proposed.**

***Keywords:* header compression, high voltage Power Line Carrier communication, IP-networks.**

I. Introduction

In the power utilities Digital Power Line Carrier (dPLC) channels over High Voltage Lines (HVL) are widely used for voice and data transmission. It should be noted that PLC have not lost its significance even with the advent of OPGW technology. PLC equipment is widely used for 35/110/220 kV power lines.

Talking about convergent solutions with dPLC the networks built by SIEMENS AG with the use of Frame Relay Access Devices (FRAD) as node equipment is the prime example of successful technical solution. DPLC Frame Relay (FR) networks were organized in the period of 2002-2009 in the countries of Latin America, Asia, Africa and CIS. In many projects, the author was personally involved.

Outdated Frame Relay, removal of Frame Relay multiplexer production, and IP traffic transmission requirements updates led to the need to shift from Frame Relay technology to IP technology. Let's mark that discussing questions related to IP-traffic transmission, we will repeatedly refer back to the experience of creation of FR networks. It is necessary to explain what will be the cost of technology transition and what way is the most efficient.

II. The Variants of IP-traffic Transmission via dPLC Links

Let's start from analysing the functionality of modern dPLC equipment for IP traffic transmission. It should be mentioned that in most modern devices function of Ethernet Bridge is integrated. At first glance it is the easiest way of IP networks organization. The use of widely spread Ethernet interface allows to connect any network equipment directly to the PLC terminals. In this case the PLC terminal participates in packet processing, and it defines PLC terminal as network element.

It can make traffic filtering, control, QoS procedures and etc. Depending on producer decision the functions might be absolutely different. Structural scheme of IP-PLC link with application of Ethernet Bridge is shown in Fig.1.

A significant disadvantage of Ethernet Bridge is a big size of the header S_{L2} of the data link layer protocol Ethernet, equal to 26 bytes. DPLC channels are inherently low speed. In most cases the speed of data transmission does not exceed few tens of kilobits per second. Therefore, a large volume of overhead information leads to a reduction of channel efficiency Eff in link with the initially small data rate.

Turning back to the rich heritage of the FR networks, we can see that the size of the header S_{L2} was equal to only 6-8 bytes that is several times smaller in comparison to Ethernet Bridges. We ask the question whether it is possible to minimize the size of the S_{L2} in IP-based networks. The answer is: in order to reduce the size of the header of the data link layer protocol it is necessary to use PPP-encapsulation of Ethernet frames. But in this case, the IP-router should be connected to the dPLC over serial interface, such as X.21 or V.35.

It should be admitted that the choice of network equipment in this case is limited because many manufacturers do not use serial interface modules in their routers. But this solution has two distinct advantages over Ethernet Bridges. The use of serial WAN connection and PPP-encapsulation reduces the size of the link layer header up to 8 bytes. DPLC equipment is not involved in the packet processing, it just converts electrical signal of X.21 interface to high frequency (HF) signal and vice versa. It simplifies the architecture of dPLC devices that in turn reduces its cost. It also reduces time of channel recovery in case of loss of synchronization between modems. Using Ethernet Bridges it is necessary to consider the time of data exchange between network elements of dPLC devices following after recovering of synchronization between modems. From the author's practical experience the time of channel recovery for Ethernet Bridge links exceeds the time of link with serial WAN connection more than 3 times.

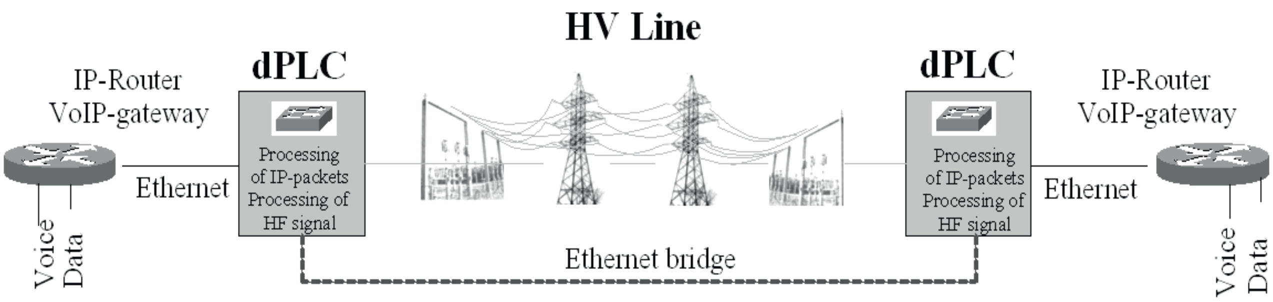

Fig. 1. Structural scheme of IP-PLC link with Ethernet –Bridge.

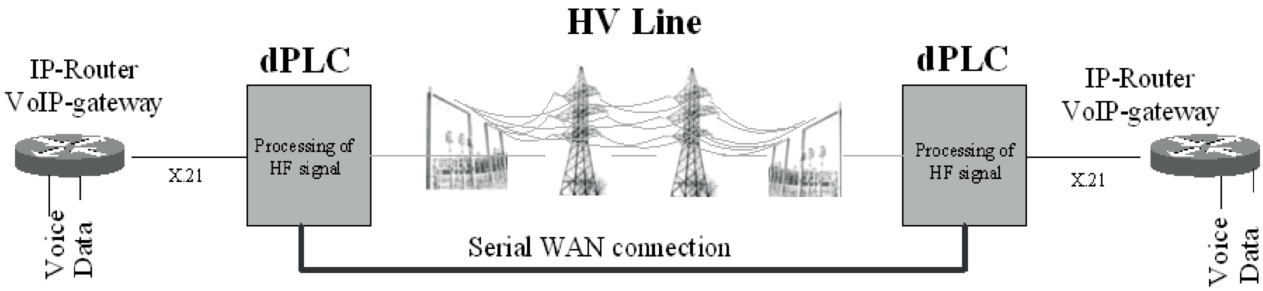

Fig.2. Structural scheme of IP-PLC link with serial WAN connection.

Another advantage of serial interfaces relates to the existing dPLC FR networks. The use of interface X.21 allows replacing FRAD multiplexers on IP routers and upgrading FR network without necessity to substitute the dPLC equipment. The structural scheme of IP-PLC link with serial WAN connection is shown in Fig.2.

At the network and transport layers in IP-networks its own headers are formed, which lead to further reduction of the channel efficiency. It should be noted that henceforth the IP protocol will be considered only in 4th version as widely used in the corporate communications networks.

III. Comparison of Ethernet Bridges and Serial WAN Connections

So, we need to compare the channel efficiency for Ethernet Bridge and serial WAN connection. For this we need to calculate the part of the payload in VoIP and in data frames.

The size of VoIP packet S_{VoIP} will depend on type of voice codec. Using a low bit-rate codecs ACELP or MP-MLQ the size of IP-datagram S_{Load} is equal to 20 or 30 bytes. The total size of IPv4/UDP/RTP header $S_{IP/UDP/RTP}$ in VoIP packet is equal to 40 bytes. For calculation of frame size and channel efficiency Eff_{VoIP} for voice frames (1) and (2) formulas are used. The results of calculation are shown in Table 1

$$Eff_{VoIP} = \left(1 - \frac{S_{L2} + S_{IP/UDP/RTP}}{S_{VoIP}}\right) \cdot 100\% \quad (1)$$

$$S_{VoIP} = S_{IP/UDP/RTP} + S_{Load} \quad (2)$$

TABLE I

Results of Calculation of S_{VoIP} and EFF_{VoIP}

L2 Protocol	S_{L2}, bytes	$S_{IPv4/UDP/RTP}$, bytes	S_{Load}, bytes	S_{VoIP}, bytes	Eff_{VoIP}, %
PPP	8	40	20	68	29,41
			30	78	38,46
Ethernet	26		20	86	23,26
			30	96	31,25

Calculation shows that in best case Eff_{VoIP} does not exceed 40%, while the use of Ethernet Bridge is the worst variant (Eff_{VoIP} = 23,26%).

We return to the dPLC Frame Relay networks. For the VoFR technology channel efficiency Eff_{VoFR} is 71.4% and 78.9% for voice packets with size of 20 or 30 bytes, respectively. Due to the size of headers Eff_{VoIP} is much lower than Eff_{VoFR}. It means, ceteris paribus, that it is necessary to expand bandwidth of dPLC channels. In most cases it is not possible because of deficit in available frequencies in band of high voltage Power Line Carrier Systems.

It will be more complicated to analyse data packets, because initially we do not know the exact size of maximum transport unit (MTU) which can vary from 46 to 1500 bytes. Since we consider convergent channels, it is necessary to take into account an important requirement - the time of data packets processing should be minimal, in order to provide speech transmission with minimal delay. But the size of the frame should not be too small to be in vain not to increase the share of the overheads. Serialization delay T_{serial} is the time that is necessary for processing of layer 2 frame from the first to the last bit and defines by formula (3). This is a factor that limits the acceptable size of frame.

T_{serial} depends on the size of frame S_{Data} and data rate C:

$$T_{serial} = \frac{8 \cdot S_{Data}}{C}, \qquad (3)$$

where

$$S_{Data} = S_{L2} + S_{IP/TCP} + S_{MTU} \qquad (4)$$

Recommended value of serialization delay should not exceed 10-15 ms [1]. For dPLC channels to meet this requirement is extremely difficult, explain why. It is clear that the greater capacity of the communication channel, the greater may be the size of data frame at a predetermined T_{serial}. The minimum size of the payload (MTU) for Ethernet is limited by 46 bytes. For guaranteed data transmission TCP protocol is used. The total size of IPv4/TCP headers $S_{IP/TCP}$ is 40 bytes. Consequently, for minimum MTU, the size of Ethernet frame will be equal to 112 bytes and PPP frame – 94 bytes.

The results of T_{serial} calculation for Ethernet and PPP protocols on dependence of data rate and the calculation of the maximum frame size of data for a given serialization delay of 10 ms are shown in Table 2.

Required serialization delay of 10 ms is performed for PPP protocol with data rate not less than 76 kbps and for Ethernet not less than 92 kbps. For dPLC links with 4 and 8 kHz bandwidth such data rate cannot be reached at all. Therefore minimum MTU size needs to be used regardless on data rate. Calculation of the channel efficiency Eff_{Data} for data transmission with the minimum size of MTU gives the following results: PPP-50%, Ethernet – 42%. At the maximum possible speed for dPLC channels in the 320 kbps, S_{data} can be increased up to 400 bytes, Eff_{Data} will be equal to 88-83% accordingly.

IV. Application of Header Compression

Reduction of the amount of overhead for transmission of IP packets can be achieved by compression of the headers. The packet consists of two parts - a header and payload. In IP networks, after session establishment the most part of fields of header are static during the session time, and some fields could be inferred. Fig. 3 and Fig. 4 shows the structure of headers IPv4/UDP/RTP and IPv4/TCP and characteristics of its fields [2].

TABLE II
Results of Calculation of Tserial and SData

C, kbps	T_{Serial} (PPP), ms	T_{Serial} (Ethernet), ms	S_{Data}, byte
22000	34,2	40,7	
36000	20,9	24,9	
50000	15,0	17,9	with minimum MTU size
64000	11,8	14,0	
76000	9,9	11,8	
92000	8,2	9,7	115
114000	6,6	7,9	143
128000	5,9	7,0	160
144000	5,2	6,2	180
192000	3,9	4,7	240
190000	4,0	4,7	238
256000	2,9	3,5	320
320000	2,2	2,8	400

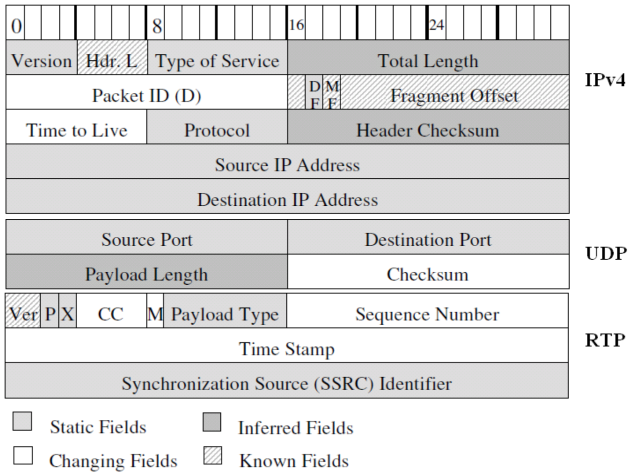

Fig.3. Characteristics of fields of IPv4/UDP/RTP header.

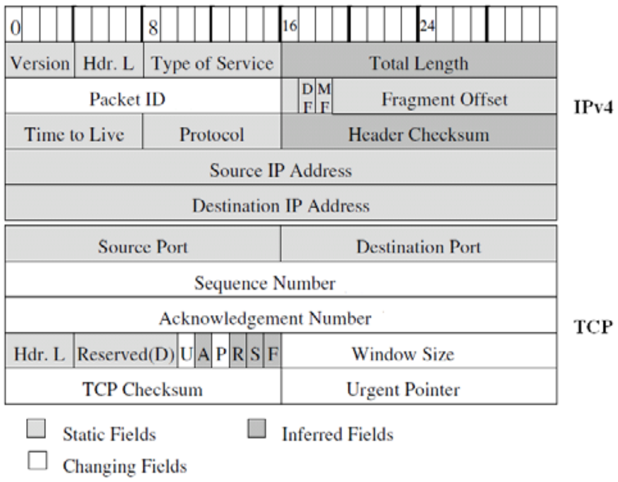

Fig.4. Characteristics of fields of IPv4/TCP header.

In 1990, CISCO software engineer Van Jacobson suggested to use IP header compression on the basis of statement that during session the most part of field in packet headers is static or rarely changing. In the same year the document RFC 1144 was published, describing header compression fundamentals. Today this technique is known as Van Jacobson Header Compression. Nowadays existing compression techniques can be divided into two groups. The first group includes methods where transmission of delta values of varying fields is used. It includes methods RFC 2507 IPHC, RFC 2508 cRTP, RFC 3545 ECRTP. Its use for PPP connection is described in the document RFC 3544 "IP Header Compression over PPP". All these methods are implemented in practice in CISCO routers and use for the serial WAN connections with PPP-encapsulation. The second group includes methods ROHC (Robust Header Compression) RFC 3095 ROHC, RFC 4996 ROHC-TCP profile, RFC 5225 ROHC v2. In these methods information about changing fields is transferred with the use of Window Based Least Significant Bit Encoding. In most cases methods of ROHC are used in wireless communication. Table 3 shows the characteristics of the existing header compression methods.

The basic characteristics of header compression methods are: compression ratio showing the decrease of the header size after compression, scheme of compressed headers transmission and immunity.

Compression ratio is calculated by the formula (5) [6]:

$$G = 1 - \frac{S_C}{S_U} \tag{5}$$

where

S_C – compressed header size, bytes;

S_U - uncompressed header size, bytes.

In most cases transmission of compressed headers is performed with application of frames. In the beginning of the session N packets with uncompressed headers are transmitted.

Refreshing of the session context is performed by transmission of uncompressed header in the beginning of each following frame with number of packets F. This scheme is particularly effective when there is no feedback between the decompressor and the compressor, since in this case the context update request is impossible. According to the results of the research represented in [7] frame size must be equal to 10 packets to provide high compression ratio even for high values of bit error rate (BER). It should be noted that in practice the size of frame and scheme of compressed headers transmission depends on compression algorithm realized by equipment developers.

Considering F:

$$G = 1 - \frac{\left(\frac{N \cdot S_U + (F-N) \cdot S_C}{F \cdot S_U} + \frac{(Q-F)}{F} \cdot \frac{(S_U + (F-1) \cdot S_C)}{F \cdot S_U} \right)}{\frac{Q}{F}} \tag{6}$$

where

Q – total number of packets transmitted during the session.

TABLE III
Characteristics of Header Compression Methods

RFC	Method	Characteristics	Implementation
1144	Van Jacobson Header Compression «VJHC»	IPv4/TCP from 40 to 4-7 bytes	CISCO routers [3] dPLC equipment PowerLink 50/100 (SIEMENS) [4] ETL 600 (ABB) [5]
2507	IP Header Compression «IPHC»	IPv4/TCP from 40 to 4-7 bytes IP/UDP from 28 to 2-5 bytes	CISCO routers
2508	Compressed Real Time Protocol «cRTP»	IPv4/UDP/RTP from 40 to 2-4 bytes	CISCO routers
3095	Robust Header Compression	IPv4/UDP/RTP from 40 to 1-4 bytes	EFFNET controller[6] dPLC equipment PowerLink 50/100 (SIEMENS) [4] ETL 600 (ABB) [5]
3545	Enhanced Compressed RTP (ECRTP)	IPv4/UDP/RTP from 40 to 8-12 bytes	CISCO routers
4996	Robust Header Compression TCP Profile	IPv4/TCP from 40 to 4 bytes	EFFNET controller [6]

The formula for calculation of average compression ratio G* during the session can be represented as (7):

for $Q \to \infty$:

$$G^* = 1 - \frac{(F-1) \cdot S_C + S_U}{F \cdot S_U} \tag{7}$$

Using (7) we find the value of the average size of compressed header during the session S_C^*:

$$S_C^* = S_U \cdot \left(\frac{(F-1) \cdot S_C + S_U}{F \cdot S_U} \right) \tag{8}$$

Immunity is determined by the compression method resiliency in case of errors in the packets and their losses. According to EFFNET company researches the best immunity have ROHC methods and ECRTP. Compression ratio of ECRTP is significantly lower than ROHC one, because transmission of absolute values of changing fields instead of delta values is used.

Using (5), (7) and (8) we make the calculation of G, G^*, S_C^*. The size of compressed header S_C is assumed as maximum possible according to data shown in Table 3. Results of calculations are represented in Table 4. We can see that the size of compressed header is significantly reduced in comparison with uncompressed header.

TABLE IV
Results of G, G* , SC*, Calculations

Method of compression	S_C, bytes	G	S_C*, bytes	G*
VJHC/ cRTP (IPv4/UDP/RTP 40 bytes)	4,0	0,90	≈ 8	0,81
ECRTP (IPv4/UDP/RTP 40 bytes)	12,0	0,70	≈ 15	0,63
ROHC (IPv4/UDP/RTP 40 bytes)	4,0	0,90	≈ 8	0,81
IPHC (IPv4/TCP 40 bytes)	7,0	0,83	≈ 10	0,74
ROHC-TCP (IPv4/TCP 40 bytes)	4,0	0,90	≈ 8	0,81

Finally we need to perform the calculation of the Eff_{VoIP} with the use of header compression. The results of calculations are shown in Table 5. For comparison the data for the VoFR technology is shown. The greatest benefit of compression can be achieved using PPP-encapsulation techniques and ROHC or cRTP compression. In this case channel efficiency increases almost twice and differs from the dPLC Frame Relay networks values not more than 13-16%. For Ethernet Bridge the benefit is not so significant.

TABLE V
Results of EffVoIP Calculation Given the Use of Header Compression

Payload, byte	Protocol L2	Eff_{VoIP}, %				
		Without header compression	cRTP	ECRTP	ROHC	VoFR (L2=8 bytes)
20	PPP	29,41	55,56	46,51	55,56	71,43
	Ethernet	23,26	37,04	32,79	37,04	
30	PPP	38,46	65,22	56,60	65,22	78,95
	Ethernet	31,25	46,88	42,25	37,04	

For data packets the gain from use of IP header compression can be expressed in opportunity to:

1) Reduce the serialization delay on size of ΔT_{serial} and become closer to the recommended value of T_{serial}:

$$\Delta T_{serial} = \frac{8}{C} \cdot \left(S_{Data} - (S_{Data} + S_C^* - S_U)\right) = \frac{8}{C}\left(S_U - S_C^*\right) \quad (9)$$

2) Increase the size of MTU on ΔS_{MTU} for the same serialization delay:

$$\Delta S_{MTU} = S_U - S_C^* \quad (10)$$

In the first case the delay is reduced, in the second one speed of information transmission is increased. For applied tasks the use of header compression allows to increase the size of the transport block by 30-34 bytes without increase of the serialization delay. For example, instead of 46-byte MTU size 80 bytes can be used. It means that in one packet almost twice more information will be transmitted, that in turn will increase the channel efficiency *Eff*.

V. APPLIED TASKS OF IP-NETWORKS CREATION VIA DPLC

We consider applied tasks of IP networks building over dPLC links. Available on the market DPLC equipment allows realizing IP networks scenarios with the use of Ethernet Bridges and PPP connections. As was shown above, the use of header compression is necessary to increase the channel efficiency.

Compression methods cRTP, ECRTP, VJHC and IPHC are implemented in CISCO routers, but in this case connection to dPLC equipment must be carried out via the serial interface X.21.

Practical application of the most advanced ROHC methods is complicated by the necessity to integrate them into dPLC equipment. The leading companies that deal with the development, adaptation and implementation of ROHC are Swedish «EFFNET» and German «Acticom Mobile Networks». But in order to use their technical solutions the license is needed. Two biggest manufacturers of dPLC equipment SIEMENS AG and ABB already integrated compression ROHC (RFC 3095) and VJHC (RFC1144) into functions of their devices PowerLink 50/100 and ETL 600. In both cases, technical solution from EFFNET was used. Since in both devices Ethernet Bridge is used, *Eff* does not increase too much. For VoIP packets Eff_{VoIP} increases by no more than 4-6% in comparison to the uncompressed header transmission. For data packets everything depends on the size of MTU. For the minimum size of MTU Eff_{Data} increases on 15%.

Using IP routers with serial interfaces and PPP encapsulation eliminates the problem of large size of the data link layer protocol header. For VoIP packets, even for compression technique ECRTP, increase of Eff_{VoIP} will be more than 17%. Using IPHC compression technique for headers of data packets Eff_{Data} will increase more than 22%.

As result of performed research we can propose the development of converter in which PPP encapsulation is used, and for header compression ROHC techniques (RFC 3095) ROHC-TCP (RFC 4996) are used. In case of external rendition such converter can be used with dPLC equipment and network equipment of any manufacturers. Interconnection with dPLC is performed via serial interface, with network equipment – via Ethernet. This solution simplifies architecture of dPLC devices and reduces its cost. Structural scheme of IP-PLC link for suggested solution is shown in Fig.5.

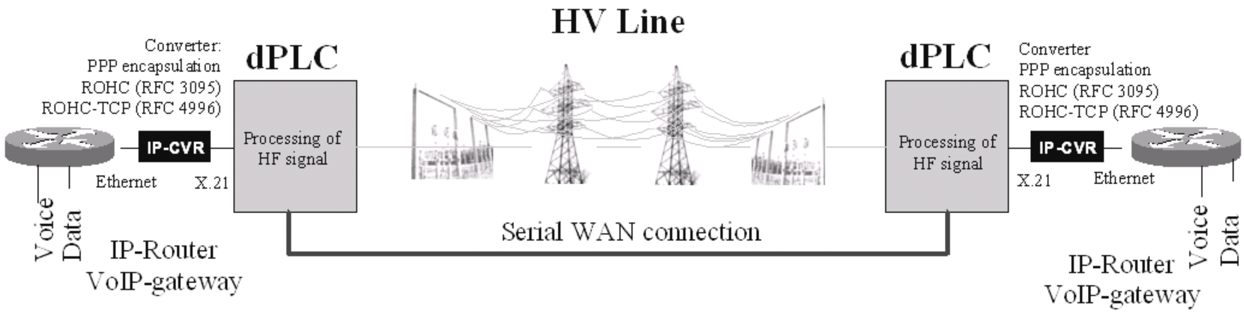

Fig.5. Structural scheme of IP-PLC link with using of external converter for header compression.

VI. Conclusion

1) Transmission of IP packets in dPLC networks with uncompressed headers leads to inefficient use of channel, because most of the resources are spent on transmission of overheads.

2) The use of header compression reduces the size of the header for VoIP packets up to 1-12 bytes and for data packets up to 4-7 bytes depending on type of compression techniques.

3) ROHC techniques provide the best compression ratio and high immunity, but its practical use is associated with the necessity to integrate compression algorithm into dPLC device. The simplest practical solution: the use of IP routers which perform header compression with the use of cRTP, ECRTP and IPHC techniques.

4) The use of Ethernet Bridges in dPLC networks is inefficient solution, because of the big size of L2 header. The best solution is application of PPP-encapsulation.

5) Interconnection of IP routers and PLC equipment via serial interface e.g. X.21 allows to avoid involvement of dPLC in packets processing. It reduces the total time of packet processing in the network and reduces the costs of additional functions of dPLC.

6) Creation of proposed converter will allow using the resources of channel capacity with the maximum efficiency.

References

[1] Design Best Practices for Latency Optimization.: CISCO, 2006. 8 p.
[2] J. A. Ishac, “Survey of Header Compression Techniques,” NASA/TM 2001-211154. 2001. Glenn Research Centre, Cleveland, Ohio. 27 p.
[3] Header Compression.: CISCO, 2012. 6p.
[4] Power Line Carrier PowerLink 100 CSPi Manual.: Siemens AG, 2011. 620 p.
[5] Power Line Carrier ETL 600 Manual:. ABB, 2011. 440 p.
[6] Compressed Time-to-Market for Compressed Headers – With EFFNET ROHC Software on Freescale Devices: Effnet, 2008. 12 p.
[7] P. Seeeling, M. Reisslein, P. T. Madsen, and F. Fitzek, “Performance Analyses of Header Compression Schemes in Heterogeneous Wireless Multi-Hop Networks,” Wireless Personal Communications (2006) 38: pp. 203–232.