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RESEARCH OF THE THROUGHPUT FOR SHDSL EFM SYSTEMS IN PAIRS AGGREGATION MODE

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Background. In modern access networks based on copper cable, EFM is widely used. This technology, using the PAF function, allows you to unevenly distribute data stream between pairs of cables depending on their quality. However, the function of PAF decreases the throughput of the transmission system due to the additional fields in PAF data frame. In addition, there is crosstalk interference between pairs, which also reduces the throughput of the connection. Therefore, research of impact of these two factors on EFM transmission systems throughput is the actual task.

Objective. The purpose of the paper is theoretical research of the throughput for multipair SHDSL EFM connection depending on number of aggregated pairs and distance.

Methods. Study all known publications and standards concerning EFM technology. Analyzing frames' format for protocols used for SHDSL systems with EFM to calculate relation between payload and special data. Research of crosstalk interference impact on SHDSL EFM link throughput.

Results. The theoretical results concerning the throughput which can be achieved in multipair mode.

Conclusions. Methods of research and their results may be used for estimation of the real throughput of SHDSL EFM links during the planning and project process.

Keywords: SHDSL; EFM; throughput; PAF; NEXT; FEXT

In the modern access networks built on the copper cable, technology of EFM (Ethernet in the First Mile) is widely used. This technology is standardized by the International Institute of Engineers of Electronics and Electrical engineering (IEEE), driven to the standard of IEEE 802.3, clause 5 and is called 2base - TL. This standard is modified version of well-known G.SHDSL technology (ITU-T G.991.2). There are two differences between G.SHDSL and EFM. First of them is encapsulation method for Ethernet-frames. G.SHDSL standard uses HDLC protocol and EFM uses 64/65B frame instead. Also, in multipair mode EFM uses PAF algorithm (PME Aggregation Function - function for transceivers aggregation) and G.SHDSL simply distribute Ethernet frame between pairs on per bytes basis.

Using the EFM technology we are facing a few factors that reduce the throughput of the transmission system. First of all, this is PAF protocol itself. Protocol PAF has additional fields which are used for control functions. Data in these fields occupies some part of the links capacity. Secondly, at the multipair mode there is a crosstalk between pairs, that create an interference which also decrease throughput. Therefore, research of simultaneous influence of these two factors on the throughput is an actual task and

results will help to more precise planning of the access network based on copper cable. Also, it will help in installation and operation processes.

To quantify the decrease of the throughput under the influence of the PAF protocol and transitional factors, the coefficient is used:

$$K = K_{PAF} * K_{ct},$$

where: K_{PAF} - coefficient of throughputs decreasing due to the PAF algorithm factor; K_{ct} - coefficient of throughputs reducing due to crosstalk between pairs.

Therefore, throughput for EFM link will be defined as:

$$C_{\Sigma} = \sum_{i=1}^m C_i * K_i,$$

where: C_i - throughput for one pair in case of crosstalk is absent and $K_{PAF} = 1$.

At first lets study impact of PAF procedure on EFM link throughput. PAF principals [1, 2] are shown on Fig. 1.

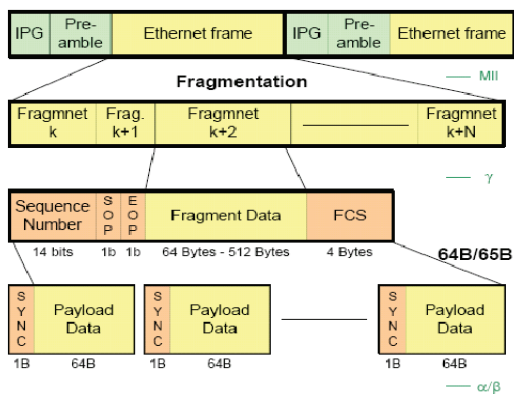


Fig 1. PAF principals

During the PAF procedure all Ethernet frames are being segmented into fragments 64... 512 bytes long depending on initial Ethernet frame size. Exceptions are Preamble and IPG (Inter Packet Gap). In order to reconstruct initial Ethernet frame at receiving point, fragments numbers are added. Fragment number consists of 14 bits. Also, SOP (Start Of Packet) and EOP (End Of Packet) per one bit each are present. Combination of these bits shows to which part of initial Ethernet frame fragment belongs to (beginning, middle or end). Check sum named FCS (Fragment Control Sequence) completes the fragment and has length of 4 bytes. All fragments are being distributed between PME's depending on transmissions speed which is set in them. Numbers of fragments are assembling in integral Ethernet frame at the opposite side of line. Due to adding the special fields (6 byte length) during the PAF procedure the decreasing of the bandwidth coefficient usage in comparison with one pair mode should be expected. For example, shortest fragment includes 70 bytes were 64 bytes are payload and longest fragment has 518 bytes (512 bytes are payload). Therefore, PAF procedure decreases the throughput for expected $K_{PAF} = 0.91...0.98$.

Crosstalk impaction on EFM link was estimated as follows.

Coefficient K_{ct} which defines the decreasing of throughput due to crosstalk between pairs can be found as:

$$K_{ct} = h_{ct}^2/h_o^2, \text{ or } K_{ct, dB} = h_{ct}^2 - h_o^2,$$

where: h_{ct}^2 – ratio of signal energy for 1 bit to spectrum density “white” noise and crosstalk interference at receiving point; h_o^2 – ratio of signal energy for 1 bit to spectrum density of “white” noise only.

Ratio h_o^2 can be written as:

$$h_o^2 = Ps/(R*N_0), \text{ or } h_{o, dB}^2 = Ps - R - N_0,$$

where: Ps – signals power at the receiving point; R – data rate; N_0 – spectrum density of “white” noise at the receiving point.

Spectrum density of “white” noise is not depended on frequency and equal minus 120 dBm/Hz, or 10^{-12} mW/Hz according to accepted model of noise.

Power of signal at receiving point can be found as:

$$Ps = \int_{F1}^{F2} (PSDtx(f) / L(f)) df,$$

where: $PSDtx(f)$ – signals spectrum density at the transmitter output; $L(f)$ – signal losses in copper cable; $F1 = 5$ kHz – minimum frequency for TC-PAM16/32/64/128 line signal which is defined by the transformer at the output of the transceiver; $F2 = f_{sym}$ – maximum frequency of line spectrum TC-PAM signal according to mask [3]; $f_{sym} = (R+8000)/K$ – modulations symbol rate; K – quantity of information symbol in modulation block (TC-PAM16 – 3, TC-PAM32 – 4, TC-PAM64 – 5, TC-PAM128 – 6).

Signal spectrum density at the transmitter output is defined as [3,4]:

$$PSDtx(f), \text{ dBm/Hz} = \frac{PSHDSL}{135} \times \frac{1}{f_{sym}} \times \left(\frac{\sin(\frac{\pi f}{f_{sym}})}{\frac{\pi f}{f_{sym}}} \right)^2 \times \frac{1}{1 + (\frac{f}{F_{3dB}})^{2 \times order}} \times \frac{f^2}{f^2 + F1^2},$$

where: $PSHDSL = 7,86$ ($R < 2048$ kbps) and $9,90$ ($R \geq 2048$ kbps) – scales coefficient; $F_{3dB} = f_{sym}/2$ – bandwidth of output filter at 3dB level; $order = 6$ – order of output filter.

Losses of signal power in copper cable line can be defined as follows [5]:

$$L(f), \text{ dB} = D \times 8,69 \times \sqrt{\frac{1}{2} (rg - lc(2\pi f)^2 + Y)},$$

where: D , km – cable length; r , g , l , c – resistance, conductivity of cable isolation, inductance and capacity of cable pair respectively; f – frequency.

$$Y = \sqrt{(r^2 + l^2(2\pi f)^2)(g^2 + c^2(2\pi f)^2)}$$

Ratio h_{ct}^2 , which related to crosstalk interference, looks like this:

$$h_{ct}^2 = Pc/R(N_0 + N_{ct}),$$

where: N_{ct} – average spectrum density of NEXT and FEXT interference.

Taking into account that NEXT approximately in 10 times less than FEXT, it is reasonable to calculate N_{ct} for NEXT only.

In this case N_{ct} can be drawn as:

$$N_{ct} = \frac{1}{F_2 - F_1} \int_{F_1}^{F_2} \sum_{i=1}^{m-1} \frac{PSD_{txi}(f)}{NEXT_i(f)},$$

where: $NEXT_i(f)$ – crosstalking between pairs on near end as a function from frequency; m – number of copper pairs which are being used.

$$NEXT_i(f), dB = NEXT_i(f=1000\text{ kHz}) - 15lg(f/1000)$$

Accordingly to approaches above and taking into account the PAF algorithm losses the calculations of throughput as line length function for one pair in 50-pairs cable were performed. Initial data: line code TC-PAM128, NEXT=60 dB at frequency of 1000 kHz, SNR margin 4 dB. Results are shown in Tab. 1 and Fig. 2.

Table 1. One pair throughput as function of cable length

D, km	1	2	3	4	5	6	7	8
m=1	15,4	15,4	10,6	6,6	4,5	3,2	2,3	1,6
m=2	15,4	13,6	7,5	4,9	3,4	2,4	1,7	1,1
m=4	15,4	12,0	6,7	4,4	3,1	2,2	1,5	0,9
m=8	15,4	10,9	6,1	4,0	2,8	1,9	1,3	0,7

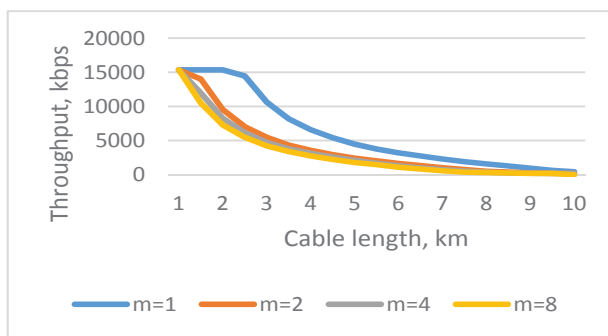


Fig. 2. One pair throughput as function of cable length for different m

From the above results it can be seen that when adding to the initially one-pair xDSL interface at least one more pair, the throughput of the line is sharply reduced (up to 30%), especially in the range of distances of 2 ... 3 km, which are the most frequently used. The reason for this is the crosstalk interference, which is much larger than the “white” noise in the cable. By itself, the PAF algorithm has a small effect (from 2 to 9%) on the throughput of the line. Thus, it can be assumed that precisely the crosstalk interferences are the factor that significantly reduces the throughput of the line. In order to reduce the level of interference, it is necessary to maintain the parameters of the cable in the normal way, especially for a parameter such as longitudinal conversion loss (LCL). You also need to pick up the cable pair carefully. The method of selecting pairs is given in the manual [4].

Conclusions

The PAF protocol reduces the throughput of the line by 2 ... 9% depending on the initial size of the Ethernet frames.

Crosstalk interference significantly reduces the throughput of the line even when using a cable with passport characteristics

To reduce the loss of the throughput of the line, it is necessary to maintain the parameters of the cable in the normal way and to select for operation of a pair with minimal mutual influence

References:

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Носков В.І.

Дослідження перепускної здатності системи SHDSL EFM у режимі агрегації пар

Проблематика. Сучасних мережах доступу, що використовують мідний кабель, поширена технологія EFM. Ця технологія у режимі агрегації пар використовує функцію PAF, яка дозволяє нерівномірно розподіляти потік даних між парами у залежності від їх якості. Однак, функція PAF знижує перепускну здатність системи передачі внаслідок службових полів у форматі фрейму, що використовується. Додатково, істотну роль в зниженні перепускної здатності відіграють перехідні завади. Таким чином, дослідження впливу цих двох факторів на перепускну здатність системи SHDSL EFM є актуальною задачею.

Мета досліджень. Теоретичні дослідження перепускної здатності для багатопарного з'єднання SHDSL EFM у залежності від кількості пар, що агрегуються, та відстані.

Методика реалізації. Аналіз всіх відомих публікацій та стандартів, присвячених технології EFM. Аналіз форматів фреймів протоколів, що використовуються в SHDSL системах з EFM, з метою вираховання співвідношення між корисними та службовими даними. Дослідження впливу перехідних завод на перепускну здатність ліній SHDSL EFM. **Результати досліджень.** Теоретичні результати відносно перепускної здатності лінії, які можуть бути досягнуті у багатопарному режимі.

Висновки. Методика досліджень та одержані результати можуть бути використані для оцінки реальної перепускної здатності ліній SHDSL з EFM у процесі планування та проектування мереж доступу.

Ключові слова: SHDSL; EFM; перепускна здатність; PAF; NEXT; FEXT

Носков В.И.

Исследование пропускной способности системы SHDSL EFM в режиме агрегации пар

Проблематика. В современных сетях доступа, использующих медный кабель, широко используется технология EFM. Эта технология в режиме агрегации пар использует функцию PAF, которая позволяет неравномерно распределять поток данных между парами в зависимости от их качества. Однако, функция PAF снижает пропускную способность системы передачи вследствие служебных полей, содержащихся в формате используемого фрейма. Дополнительно, существенную роль в снижении пропускной способности линии играют переходные помехи. Таким образом, исследование влияния этих двух факторов на пропускную способность системы SHDSL EFM является актуальной задачей.

Цель исследований. Теоретические исследования пропускной способности для многопарного соединения SHDSL EFM в зависимости от количества агрегируемых пар и расстояния.

Методика реализации. Анализ всех известных публикаций и стандартов, посвященных технологии EFM. Анализ форматов фреймов протоколов, которые используются в SHDSL-системах с EFM, с целью вычисления соотношений между полезными и служебными данными. Исследование влияния переходных помех на пропускную способность линии SHDSL EFM.

Результаты исследований. Теоретические результаты относительно пропускной способности линии, которые могут быть достигнуты в многопарном режиме.

Выводы. Методика исследований и полученные результаты могут быть использованы для оценки реальной пропускной способности линий SHDSL EFM в процессе планирования и проектирования сетей доступа.

Ключевые слова: SHDSL; EFM; пропускная способность; PAF; NEXT; FEXT