The constructing a centralized control of engineering systems of objects of modern civil engineering

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Abstract. The effectiveness of centralized control of engineering systems of modern civil engineering projects increased in the case of high-speed cable communication channels to enable communication over IP with speeds below 100 Mbit/s with minimal latency. The ability of increasing the length of such channels for their implementation on the basis of twisted pairs cables without performing new development due to modifications of the design of serial components. The results of the theoretical analysis are compared with experimental data. Shows the possibility of at least a threefold increase in the length of the channel.

Key words: centralized control of engineering systems, modern civil engineering, high-speed IP-communication, twisted pair cable, channel length

1. Demand for the Changes of the Requirements for the Use of Twisted Pair Cables of IT Systems in Civil Engineering

Real estate projects of modern civil engineering, originally designed or adapted for permanent or prolonged stay of people in them, are necessarily equipped with a number of engineering systems. Among them, there is necessarily the complex of information and telecommunication systems (ITS). For reasons of accessible maintenance, ease expansion, increasing operational flexibility and other similar criteria, the ITS systems are built on common or ideologically very close to each other principles.

ITS traditional systems are local computer network and telephone communication network. The physical layer of these projects on the basis of standards ISO/IEC 11801, EN 50173 and ANSI/TIA/EIA-568 is implemented on the basis of structured cabling systems (SCS), which consists of several individual subsystems, forming a hierarchical structure and maintaining the LAN and phone network of the company. This approach reduces administration costs and gives an opportunity to increase the operational reliability of the ITS. The horizontal subsystem of the SCS is built on the twisted pair cables, whereas on the main levels the fiberoptic technology is mainly used.

Recently, the list of the ITS systems in modern civil engineering has significantly expanded. The systems of video surveillance, access control, engineering management of the building and several other systems with high-speed IP-communication have appeared. All of them are built on the basis of ip-equipment, for transfer of information between separate terminal and group devices, the technical means of the LAN are involved [1]. The main difference from classical analogues is that the systems of this group are drawn towards the centralized control scheme of construction and are physically separated from the rest of the network. This approach is justified by the considerations of securing the required level of protection against unauthorized access and increasing operational reliability. The
change of the original positions leads to the fact that the limitations on the twisted pairs (TP) cable channel, including the known limitation of the range of communication in 100 m no longer meet the requirements of practice.

Typical for the classical equipment of the LAN for high-speed IP-communication method on increase of the limit range of communication by switching to fiber optic technology for complex information systems in modern civil engineering is unprofitable for the following reasons:

- increased cost of the line due to the additional conversion of the electric signal into the optical one and back;
- complexity of current maintenance, change of configuration and laying of new lines by operational staff;
- difficulties in using multiplexing advantages due to the low density of the placement of controllers of the system of engineering support, cameras of video surveillance system and other terminal devices;
- impossibility of remote power supply of terminal devices with the involvement of widespread technologies of PoE and PoE+, and in the perspective of PoE++.

In favor of refusal in new ITS systems from a hierarchical scheme of construction and application of fiber optic technology, we could say that in new conditions the transport level is not required high productivity. This allows to use for its implementation on a massive scale the interfaces 100Base-TX (Fast Ethernet), which are not so demanding on the parameters of cable routes compared to a typical LAN technology 1000Base-T (1G Ethernet).

Further the ways for increase of the general efficiency of realization of physical level of the ITS in modern civil engineering are considered. In this regard

- limit length of the cable route of their TP is assessed;
- structure of the line cable is substantiated;
- possibility of using the PoE technology to support the functioning of terminal devices is determined.

2. Prerequisites for Increasing the Length of the Line in Civil Engineering and the Design Model

The twisted pair cable channel length can be increased above the standard of IEEE 802.3u value of 100 m based on the fact that:

- the specifications of the Fast Ethernet network interfaces for high-speed IP-communication were originally designed to meet the capabilities of the category 5, while the typical modern technology provides the parameters of the category 5e;
- the cable channel length can be built on a simpler direct connection scheme;
- due to the use of a twisted pair transmission scheme, the noise level at the input of the receiver is significantly reduced.

The transmission cable channel of the new ITS systems is not part of the SCS, which allows to refuse to comply with the length limitation of 100 m.

In the future we assume that

- the network interface complies with the IEEE 802.3u specification and functions in full duplex mode;
- the transmission channel is based on the direct connection scheme;
- the parameters of influence of installation and patch-cord cables are identical, and the coefficient of attenuation of a installation cable is 1.5 times less in comparison with patch-cord one;
- in the structure of the cable channel, a typical connector according to ISO/IEC 11801 standard is used.
The linear signal of the Fast Ethernet interface refers to broadband, and its range is close to the sustainable one [2]. This allows you to use the theory of C. Shannon and look for the limit length of the channel as a solution to the next equation [3]

\[ W(l) = \int_0^\infty \log_2[1 + ACR(f, l)] \, df, \]  

(1)

where \( ACR = NEXT \cdot al \) – attenuation to crosstalk ratio at the near-end; \( NEXT \) – near and cross talk loss; \( a \) – insertion loss ratio; \( l \) – “electrical” length of the channel. The lower limit of integration is set to 0, which has little effect on accuracy, but can simplify the end result.

3 Determination of the performance of the channel

For the convenience of calculation, it is convenient to represent (1) in a three-term form with a partition of the integration interval by \([0; f_b]\) and \([f_b; \infty]\), figure 1:

\[ W = I_1 + I_2 + I_3 = \int_0^{f_b} \log_2ACR(f) \, df + \int_0^{f_b} \log_2 \left[ 1 + \frac{1}{ACR(f)} \right] \, df + \int_{f_b}^\infty \log_2[1 + ACR(f)] \, df. \]

(2)

The upper frequency limit \( f_b \) is the root of equation

\[ NEXT - 15 \log(f) - al \sqrt{f} = 0. \]

(3)

Figure 1. Shannon’s performance of a twisted pair cable channel

The solution (3) by the small parameter method gives

\[ f_b = (\frac{NEXT}{al} + \varepsilon_1 + \varepsilon_2 + \ldots)^2. \]

(4)

where \( \varepsilon_1 = -\frac{13}{al} \cdot \ln\left(\frac{NEXT}{al}\right)/\left(1 - \frac{13}{al}\right) \), \( \varepsilon_2 = -\frac{\varepsilon_1 + \frac{13}{al}}{al} \cdot \ln\left(\frac{NEXT + \varepsilon_1}{al}\right) \).

In expression (4), the total near end cross talk loss \( NEXT \) of the TP cable channel appears. The self-interference, determined by \( NEXT \), is created by the cables, as well as by the near end connector. Considering the equality of parameters of the influence of line and patch-cord cables [4], as well as the construction of the patch-field according to the interconnect scheme
\[ \text{NEXT} = \text{NEXT}_0 - 15 \log f - 20 \log [1 + 0.13 f_b^{0.25}], \]

where \( \text{NEXT}_0 \) – near end cross talk of the cable, and \( f_b = 100 \text{ MHz} \).

The calculated ratios for the individual additive components (2) are shown in the Table 1. Uncertainty at the lower limit of integration eliminated the fact that \( \lim_{x \to 0} x \cdot \ln(x) = 0 \). The base of the logarithm was additionally changed and the decomposition was involved \( \ln(1 + x) \approx x \).

**Table 1. Calculated ratios for calculating \( W \)**

| Term  | Calculated ratios                                                                 | Note          |
|-------|-----------------------------------------------------------------------------------|---------------|
| \( I_1 \) | \( 0.166 \cdot \text{NEXT} \cdot f_b - 1.08 \cdot f_b \cdot (\ln f_b - 1) - 0.11 \cdot f_b^{1.5} \cdot \alpha l \) | Lower bound   |
| \( I_2 \) | \( \frac{2.88}{0.115 \alpha l} \cdot 10^{-\frac{\text{NEXT}^2}{20}} \cdot e^{0.115 \alpha l / f_b} \cdot [f_b - \frac{2 \sqrt{f_b}}{0.115 \alpha l} + \frac{2}{(0.115 \alpha l)^2}] \) | Upper bound   |
| \( I_3 \) | \( \frac{2.88 \cdot 10^{\text{NEXT}/20}}{0.144 \cdot \alpha l \cdot f_b^{1.75}} \) | Upper bound   |

4. Analysis of Results

The results of calculations on the obtained ratios are given in Table 2 and testify on the possibility of significant increase in the channel length.

For typical for the category 5e equipment \( \text{NEXT} \) values and \( \alpha \) individual additive components of \( W \) we have \( \frac{I_1}{I_1 + I_2 + I_3} \approx 0.6 \). Thus, \( I_1 \) is the main part of \( W \) and can be used as an effective estimate of the real throughput rate of a symmetric channel.

From the expression for \( I_1 \) we have

\[ \frac{\partial^2 W}{\partial f^2} = -\frac{1}{f} (1.08 + 0.15 \alpha l) < 0. \] (5)

From (5) \( W \) of the cable channel is determined by its parameters in the low-frequency part of the working spectral range.

From (3) with typical for the contemporary equipment \( \text{NEXT} \) and \( \alpha \)

\[ \sqrt{f_b} \equiv \frac{\text{NEXT}}{2 \alpha l} \] (6)

Thus, the main directions of increasing \( l \) at \( f_b = \text{const} \) are the decrease in \( \alpha \) and the increase of \( \text{NEXT} \). From (6) we have

\[ \left| \frac{\partial l/\partial \alpha}{\partial l/\partial \text{NEXT}} \right| = \frac{\text{NEXT}}{\alpha}. \] (7)

Conclusion (7) does not take into account the dependence of \( f_b \) on \( \text{NEXT} \) and \( \alpha \). It is possible to show that its presence has no significant influence on the estimation (7).

In the transition to higher categories, the typical increase in \( \text{NEXT} \) is usually around 15\%.

Considering the fact that the "electric" length of the channel is determined mainly by the line cable:

- the main means of increasing the length of the symmetric cable channel is the reduction in the attenuation ratio \( \alpha \);
for achieving the desired effect, the attenuation ratio should be reduced by at least 15%, which corresponds to units of dB/100 m at the frequency of 100 MHz.

5. Ways to Reduce the Attenuation of the Twisted Pair

Attenuation in the TP is determined by losses in:
1. metal of conductor (heat, surface effect, proximity effect) – \( \alpha_1 \);
2. insulation of conductor – \( \alpha_2 \);
3. shield – \( \alpha_3 \);
4. separator, the cover material and other similar cable components – \( \alpha_4 \) (very small).

The ratio between these components is shown in figure 2.

![Figure 2. Ratio of individual components of the losses of the TP](image)

The main contribution to the final value of \( \alpha \) is the loss of \( \alpha_1 \) in the metal, the rest of the components on the basis of [7] do not exceed 12 – 15%.

Refusal from the shields and a reduction in losses in the metal conductors can effectively reduce the value of \( \alpha \). Considering the smallness of \( \alpha_4 \) the attenuation ratio of a twisted pair cable with a U/UTP structure (\( \alpha_3 = 0 \)) is

\[
\alpha = \frac{4.34R}{Z} + \alpha_2, \tag{8}
\]

where \( Z \) – is the impedance, and \( R \) – is the active resistance.

In the first approximation it is possible to accept that \( \alpha_2 \approx 0.1 \alpha \).

It follows from (8) that it is possible to decrease \( \alpha \) by decrease of \( R \) and increase of \( Z \). The first way is more promising because it maintains a consistent load on the input and output of the interface.

The estimation of the expected value of \( \alpha \) with different source data is given in table 2. The parameters of the standard [5] were used to perform the calculations

| Diameter of conductor, mm | 0.5 | 0.52 | 0.55 | 0.6 | 0.64 |
|---------------------------|-----|------|------|-----|-----|
| \( Z = 100 \) Ohm, dB/100 m | 21.5 | 20.0 | 18.2 | 15.6 | 14.0 |
| Length, m                 | 185 | 202  | 226  | 258 | 288 |
| \( Z = 120 \) Ohm, dB/100 m | 18.3 | 16.3 | 14.8 | 12.8 | 11.5 |
| Length, m                 | 221 | 251  | 268  | 311 | 345 |
| \( Z = 150 \) Ohm, dB/100 m | 15.1 | 13.8 | 12.6 | 10.9 | 9.9 |
| Length, m                 | 263 | 293  | 315  | 366 | 402 |
From table 2 it can be seen that decrease of attenuation due to increase in diameter of the conductive vein gives greater effect in comparison with the impedance increase.

Increasing \( W \) and \( l \) with \( NEXT \) loses at effectiveness to decreasing \( \alpha \). \( NEXT \) is minimized by decreasing the pitch \( h \) of the twist. For example, the transition from \( h = 18 \) mm (the category 5e) to \( h = 7 \) mm (the category 6) gives the growth of \( NEXT \) by 10 dB. At the same time, \( R \) grows, the increment of which is 2.4%. At a frequency of 100 MHz it gives an increase of \( \alpha \) on 0.12 dB and reduces the limit length of a channel by significant for practice 5 m.

![Image of camera and PoE module](image)

**Figure 3.** Camera of IP-video surveillance system with a line length of 200 m and its parameters

### 6. Limitations on the Maximum Length of the Twisted Pair Channels using PoE technology

In the ITS construction, it is convenient to use the technology of remote power supply (Power over Ethernet), which limits the maximum of cable channel length. The estimation of this parameter was carried out on the basis of typical conditions for the systems of the PoE conditions [6]:

- the TP of 100 m in length with a conductor diameter of 0.5 mm at a temperature of 20 \(^\circ\)C has a loop resistance of 25 Ohm;
- the minimum output voltage of the source is 44 V;
- the input voltage of the terminal equipment is equal to 36 V.

The results of calculations are given in table 3.

#### Table 3. Calculated limit range of the system of remote power depending on the diameter of the copper conductor

| Diameter of the conductor, mm | 4-wire circuits (2 pairs) | 2-wire circuits |
|------------------------------|--------------------------|-----------------|
|                              | 0.5          | 0.52          | 0.55          | 0.6          | 0.64          | 0.8          | 0.8          | 1.0          |
| Loop resistance of the pair, Ohm/100 m, at 20\(^\circ\)C | 25            | 23.1          | 20.7          | 17.4          | 15.1          | 9.8          | 9.8          | 6.3          |
| Length of the channel, power 25.5 W | 68            | 73            | 82            | 97            | 112           | 173          | 87           | 135          |
| Length of the channel, power 13 W | 133           | 144           | 161           | 192           | 221           | 340          | 170          | 265          |
| Length of the channel, power 4 W | 432           | 468           | 522           | 621           | 716           | 1103         | 552          | 858          |
The experimental test was performed on two lines of length (figure 3):
- 200 m on the industrial cable with impedance 150 Ohm (the conductor diameter of 0.52 mm).
- 270 m on the office cable with impedance 100 Ohm (the conductor diameter of 0.64 mm).

The quality of the work was assessed visually and by the error counter [8].

7. Conclusion

1. The length of the symmetrical channel of a number of modern civil engineering, high-speed IP-communication engineering systems for centralized control can reach 400 m.
2. The main means of achieving the specified qualitative indicators is the ratio of attenuation $\alpha$, which is reduced by the increase in the diameter of the conductor.
3. Installation cables must have a U/UTP structure and the category 5e characteristics.
4. To reduce the cost of the ITS implementation, it is possible to use 2-pair versions of the U/UTP twisted pair cables.
5. Considering the relatively small need for network interfaces of "long" Ethernet in the background of the LAN, the development of new types of equipment with a transmission speed of 100 Mbit/s makes no sense.
6. With channel lengths of no more than 200 - 220 m as a means of delivering the supply voltage to the terminal equipment, it is advisable to use the twisted pairs, at large distances we must use separate non twisted conductors with diameter more as 0.8 mm.

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