TITLE	**Evaluating the crosstalk for a multi-node topology**
PROJECT	SpM-2 (study point SP2-4)
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STATUS	for discussion
ABSTRACT	This contribution provides an independent crosscheck of the multimode crosstalk formula's, proposed by Czech Telecom in TD06. It has been elaborated for a special case, where only three wire-pairs are involved. The results do not look similar, which indicates that more study is required to have this resolved.

TD06 from Czech Telecom (061t06a0) proposes expressions to evaluate the crosstalk for a multi-node topology where all LT-nodes are co-located. In this WD25, we perform an independent crosscheck of these expressions, by elaborating the crosstalk in a different way for a very simple topology. This topology involves only three wire-pairs of different lengths.

1. Used terminology in this contribution

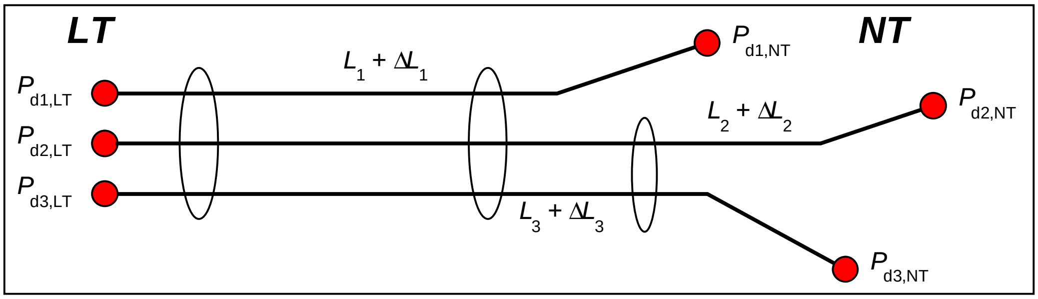
To simplify the expressions for crosstalk, we use the symbols summarized below. "HH" is a shortcut for the square for "H", the same applies for "SS", and the function "FSUM" is a shortcut for a function that cumulates many individual contributions to the overall crosstalk:

$HH_{NEXT}(f,L) = \left\|H_{NEXT}(f,L)\right\|^2$	=	Square of NEXT coupling over length *L* (see SpM2-8.2.1)
$HH_{FEXT}(f,L) = \left\|H_{FEXT}(f,L)\right\|^2$	=	Square of FEXT coupling over length *L* (see SpM2-8.2.1)
$SS_T(f,L) = \left\|S_T(f,L)\right\|^2$	=	Square of characteristic transmission of a cable, as being used in SpM2-8.2.1
$P_{dq,NT}(f)$	=	PSD of a disturber in wire-pair "q" at the NT side
$P_{dq,LT}(f)$	=	PSD of a disturber in wire-pair "q" at the LT side
$P_{XN,LT,q}(f)$	=	Cumulation of all crosstalk at LT node "q", from a near-end origin
$P_{XF,LT,q}(f)$	=	Cumulation of all crosstalk at LT node "q", from a far-end origin
$P_{X,LT,q}(f)$	=	Cumulation of all crosstalk at LT node "q" (both near and far ends)
$FSUM\begin{pmatrix}P_1\\P_2\\...\\P_N\end{pmatrix} \equiv \left(P_1^{Kn} + P_1^{Kn} + ... + P_1^{Kn}\right)^{1/Kn}$		A function (that maps a vector to a scalar, and evaluates the cumulation of different crosstalk contributions (if K_N=1/0.6, it becomes the "FSAN-sum")

2. Example topology with only three wire-pairs

In this example topology, three links (with six transceivers) are involved. This contribution elaborates the crosstalk observed by each of the six receivers, caused by NEXT and FEXT from the two other links.

The wire pairs are coupled over the length that they share the same cable; the rest of the length will cause that the crosstalk is attenuated first before it arrives at each receiver.



3. Crosstalk at each node of the example topology

To enable a cross-check with the expressions in TD06, we will elaborate first the crosstalk observed by each of the six involved receivers. Since we have restricted ourselves to a simple topology, so that the results below become simpler then the general expressions for an arbitrary number of links and node locations.

For reasons for simplicity the true termination impedances of the wire-pairs is fully ignored (commonly 100Ω or 135Ω). Instead of that, all crosstalk expressions are based on the *characteristic* transmission of all wire-pair sections (as if the wire-pair is terminated with its characteristic impedance Z_0). By doing so, a cascade of two loops can easily be evaluated by multiplying their respective characteristic transmissions.

3.1. Crosstalk at node LT#1 in the example topology (shortest path)

This paragraph evaluates the PSD level of the crosstalk, observed by an LT receiver at wire-pair #1

$$P_{XN,LT,1}(f) = \boldsymbol{FSUM}\begin{bmatrix} 0 \\ HH_{NEXT}(f, L_1) \times P_{d2,LT}(f) \\ HH_{NEXT}(f, L_1) \times P_{d3,LT}(f) \end{bmatrix}$$

$$P_{XF,LT,1}(f) = \boldsymbol{FSUM}\begin{bmatrix} 0 \\ HH_{FEXT}(f, L_1) \times SS(f, \Delta L_2 + L_2 - L_1) \times P_{d2,NT}(f) \\ HH_{FEXT}(f, L_1) \times SS(f, \Delta L_3 + L_3 - L_1) \times P_{d3,NT}(f) \end{bmatrix}$$

$$P_{X,LT,1}(f) = P_{XN,LT,1}(f) + P_{XF,LT,1}(f)$$

3.2. Crosstalk at node LT#2 in the example topology (longest path)

This paragraph evaluates the PSD level of the crosstalk, observed by an LT receiver at wire-pair #2

$$P_{XN,LT,2}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{NEXT}(f,L_1)\times P_{d1,LT}(f) \\ 0 \\ HH_{NEXT}(f,L_3)\times P_{d3,LT}(f) \end{bmatrix}$$

$$P_{XF,LT,2}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{FEXT}(f,L_1)\times SS(f,\Delta L_1)\times P_{d1,NT}(f) \\ 0 \\ HH_{FEXT}(f,L_3)\times SS(f,\Delta L_3)\times P_{d3,NT}(f) \end{bmatrix}$$

$$P_{X,LT,2}(f) = P_{XN,LT,2}(f) + P_{XF,LT,2}(f)$$

3.3. Crosstalk at node LT#3 in the example topology (medium path)

This paragraph evaluates the PSD level of the crosstalk, observed by an LT receiver at wire-pair #3

$$P_{XN,LT,3}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{NEXT}(f,L_1)\times P_{d1,LT}(f) \\ HH_{NEXT}(f,L_3)\times P_{d2,LT}(f) \\ 0 \end{bmatrix}$$

$$P_{XF,LT,3}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{FEXT}(f,L_1)\times SS(f,\Delta L_1)\times P_{d1,NT}(f) \\ HH_{FEXT}(f,L_3)\times SS(f,\Delta L_2 + L_2 - L_3)\times P_{d2,NT}(f) \\ 0 \end{bmatrix}$$

$$P_{X,LT,3}(f) = P_{XN,LT,3}(f) + P_{XF,LT,3}(f)$$

3.4. Crosstalk at node NT#1 in the example topology (shortest path)

This paragraph evaluates the PSD level of the crosstalk, observed by an NT receiver at wire-pair #1

$$P_{XN,NT,1}(f) = \boldsymbol{FSUM}\begin{bmatrix} 0 \\ HH_{NEXT}(f,L_1)\times SS(f,\Delta L_2 + L_2 - L_1 + \Delta L_1)\times P_{d2,NT}(f) \\ HH_{NEXT}(f,L_1)\times SS(f,\Delta L_3 + L_3 - L_1 + \Delta L_1)\times P_{d3,NT}(f) \end{bmatrix}$$

$$P_{XF,NT,1}(f) = \boldsymbol{FSUM}\begin{bmatrix} 0 \\ HH_{FEXT}(f,L_1)\times SS(f,\Delta L_1)\times P_{d2,LT}(f) \\ HH_{FEXT}(f,L_1)\times SS(f,\Delta L_1)\times P_{d3,LT}(f) \end{bmatrix}$$

$$P_{X,NT,1}(f) = P_{XN,NT,1}(f) + P_{XF,NT,1}(f)$$

3.5. Crosstalk at node NT#2 in the example topology (longest path)

This paragraph evaluates the PSD level of the crosstalk, observed by an NT receiver at wire-pair #2

$$P_{XN,NT,2}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{NEXT}(f, L_1) \times SS(f, \Delta L_1 + L_2 - L_1 + \Delta L_2) \times P_{d1,NT}(f) \\ 0 \\ HH_{NEXT}(f, L_3) \times SS(f, \Delta L_3 + L_2 - L_3 + \Delta L_2) \times P_{d3,NT}(f) \end{bmatrix}$$

$$P_{XF,NT,2}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{FEXT}(f, L_1) \times SS(f, L_2 - L_1 + \Delta L_2) \times P_{d1,LT}(f) \\ 0 \\ HH_{FEXT}(f, L_3) \times SS(f, L_2 - L_3 + \Delta L_2) \times P_{d3,LT}(f) \end{bmatrix}$$

$$P_{X,NT,2}(f) = P_{XN,NT,2}(f) + P_{XF,NT,2}(f)$$

3.6. Crosstalk at node NT#3 in the example topology (medium path)

This paragraph evaluates the PSD level of the crosstalk, observed by an NT receiver at wire-pair #3

$$P_{XN,NT,3}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{NEXT}(f, L_1) \times SS(f, \Delta L_1 + L_3 - L_1 + \Delta L_3) \times P_{d1,NT}(f) \\ HH_{NEXT}(f, L_3) \times SS(f, \Delta L_2 + L_2 - L_3 + \Delta L_3) \times P_{d2,NT}(f) \\ 0 \end{bmatrix}$$

$$P_{XF,NT,3}(f) = \boldsymbol{FSUM}\begin{bmatrix} HH_{FEXT}(f, L_1) \times SS(f, L_3 - L_1 + \Delta L_3) \times P_{d1,LT}(f) \\ HH_{FEXT}(f, L_3) \times SS(f, \Delta L_3) \times P_{d3,LT}(f) \\ 0 \end{bmatrix}$$

$$P_{X,NT,3}(f) = P_{XN,NT,3}(f) + P_{XF,NT,3}(f)$$

4. Observations and conclusion

When calculating crosstalk from disturbers at links with different lengths, the evaluation of the levels get complicated. The formulas above look very irregular at a first glance, and this illustrates the real challenge: how to write down an expression in a simple way that is valid for an arbitrary number of wire pairs and nodes.
At this moment, the proposal in TD06 seems not to produce the same results as above, and this has to be resolved first.

The way this is implemented in the TNO-proprietary simulation tool is by analyzing each link of an arbitrary topology, and by finding for each pair of disturbers what length it has in common with the wire-pairs of the victim (for the “HH” functions), and what additional length is involved for attenuation purposes (for the “SS” functions). It requires finding the “minimum” of two lengths, when all LT-nodes are co-located, and requires a more advanced approach for the more general case. This approach works well in a software implementation, but is not so convenient to specify for a document like SpM-2.

Therefore, further study is required to create a description that is simple, valid and unambiguous in specification, before it can be included into the SpM-2 document.