DSL Physical Layer Testing

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Over the next few blog posts, we will cover some of the basic principles of testing the performance of the Digital Subscriber Line (DSL) physical layer. Each set of DSL transceivers operates over a local loop of the telephone network. Essentially, this is a transmission line consisting of two copper conductors that are twisted together. The exact wire gauge, dielectric insulation between the conductors, and other electrical and mechanical specifications differ globally from geographic region to geographic region.

DSL transceivers employ a modulation scheme called Discrete Multi Tone (DMT). With DMT, the available channel bandwidth is broken up into multiple sub-channels, or slots. Each sub-channel carries a bit payload under its own Quadrature Amplitude Modulation (QAM) modulation scheme. The size of the QAM constellation in a sub-channel depends only on the noise conditions of that sub-channel. High noise sub-channels have small constellations with greater distance between amplitude levels, while low noise sub-channels have large constellations with smaller distance between amplitude levels. The narrow bandwidth of the sub-channel mitigates dispersive effects and makes equalization easier.

DMT's roots can be traced to the old telephone modems of the 1960s. In the 1970s and 1980s, modulation techniques like DMT were used with telephone modems, under names such as "Supermodem" and "Trailblazer." Similar techniques investigated for bandwidth constrained satellite communications in the 1970s were classified under the general category of "Close Packing." Wireless systems also use a similar modulation technique in IEEE 801.11a (WiFi) called Orthogonal Frequency Division Multiplexing (OFDM).

However, unlike these ancestors and close siblings, DSL using DMT employs a training mechanism whereby the QAM modulation of each sub-carrier is optimized to the conditions of the sub-channel. This optimization makes DSL an ideal technology for deployment over large networks (like existing copper telephone networks) of varying channel conditions, such as attenuation and interference. Two-way communication on the same local loop is allowed for through frequency division duplex techniques, allocating some of the sub-channels to each direction of transmission. These great improvements in the capabilities of DMT compared to those of its ancestors and close siblings have only been realized through the advances in Digital Signaling Processing chip technology. While the concepts may go back to the 1960s the technology to realize it did not exist then.

As with all communications performance testing, a key goal in DSL testing is to measure the system performance in an environment representative of a "real-world" deployment - the environment that service providers have to deal with, and the environment in which their customers exist. In order to define a suitable DSL test suite, this "real-world" deployment environment must be understood.

Typically, deployments use local loops configured from twisted pair copper conductors ranging in length from approximately 2,000 to 18,000 feet. These local loops are generally bundled into groups of 25 wire pairs, commonly referred to as a binder group; although in some circumstances there may be fewer local loops in the binder. Each local loop attaches to a set of transceivers - one at each end - carrying an independent single DSL connection. There is no sharing of the local loop as in Cable-TV broadband access connections.

The copper based local loop typically exhibits stationary channel attenuation, impedance, phase, and group delay characteristics. A number of standards bodies, such as ATIS and ETSI, maintain published models available for wire types around the world. Using these models, it is possible to develop accurate local loop simulators for different local loop configurations: length, cable type, etc. The local loop simulator simulates to varying degrees the attenuation, impedance, phase, and delay. One approach to simulation of the local copper loop is to utilize common transmission line model, which consists of a series resistance and inductance and a parallel capacitance and conductance (see figure 1). By creating a real implementation of this simple circuit, it is possible to simulate the local loop to varying degrees of accuracy.

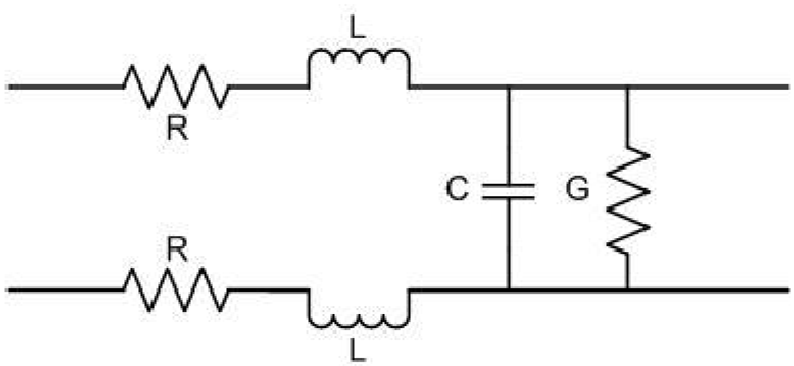

Figure 1: Common Transmission Line Model

The simulation of the copper local loop twisted pair transmission line provides only part of the complete testing solution. The DSL connection of one local loop exists inside the binder group, in close proximity to other wire pairs also carrying DSL signals. Because the proximity is maintained for long distances, DSL signals from one wire pair will radiatively couple onto another, as shown in Figure 2. The coupled signal will appear as noise source to the DSL transceivers operating over the wire pair. Again, there are published models for how the wire topology will affect this coupling, leading to a coupling function that is dependent on multiple factors, including wire type and length, levels of signals and frequency. Based on these considerations, it is possible to develop a model approximating the worst possible coupling, and thus the worst possible coupled noise conditions. Furthermore, the DSL connection will suffer from other deleterious effects, including the background Additive White Gaussian Noise (AWGN), which is present in the transceivers; Radio Frequency Interference (RFI) from AM broadcast stations, FM broadcast stations, Amateur Radio operators and other sources due to the connection to the service provider network; and impulse noise from diverse sources such as inductive motors, microwave ovens, and others.

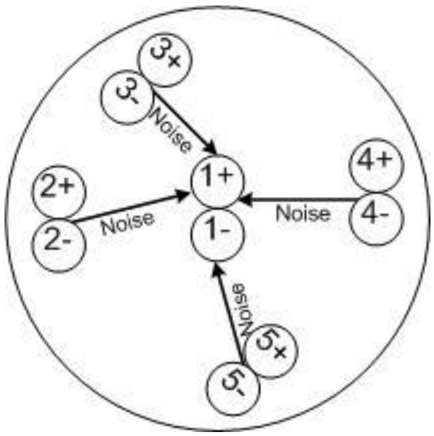

Figure 2: End view of binder group showing cross-talk noise coupling

Given these two components, the local loop transmission line model and the local loop noise models, it is possible to simulate a DSL communication channel typically utilized by transceivers in a “real-world” service provider deployment. In such a simulation, the local loop transmission line model is chosen to simulate the wire types and loop length. The noise is chosen to simulate the impairments caused by other DSL systems operating in the same binder group and other noise sources. One additional consideration is the injection of the simulated noises into the line model. It is typically the easiest to perform the injection at each side of the simulated channel. However, care must be taken in cases where the attenuation is not sufficient to attenuate the injected noises to negligible levels at the other “side” of the simulated channel, as would be the case for short local loops. In such cases, it may be necessary to test each receiver independently, injecting the noise(s) at only one “side” of the simulated channel. By using the techniques described here, it is possible to test DSL systems with repeatable performance measurements.