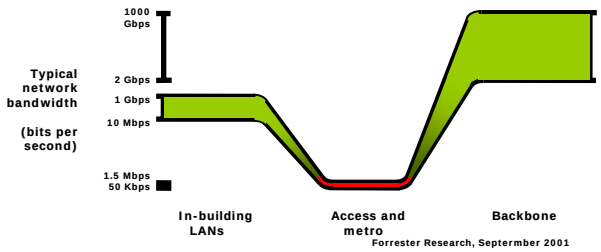
Aktino **beam**™ The next step in the Loop

In the race to supply increased bandwidth to the business user, last mile access has fallen far behind. Backbone bandwidth capacity is measured in thousands of gigabits per second and in-building LANs supply 100 Mbps and more on a routine basis. But for that 89% of business establishments served only by copper (including suburban outposts of Fortune 100 companies) the only way to tie these two broadband segments together is through a narrow, clogged 1.5 Mbps T1 pipe.



At the same time, more copper loops are becoming available due to the success of wireless telephones and ADSL. Service providers are just beginning to take advantage of this situation to generate more revenue by deploying services that bond several copper pairs to form a symmetrical broadband link.

Inverse Multiplexing and logical bonding
Several forms of inverse multiplexing, i.e. methods of combining multiple circuits into a single logical pipe, exist today, such as Multilink Frame Relay (MFR), Multilink Point-to-Point Protocol (MLPPP), Inverse Multiplexing over ATM (IMA), Ethernet Link Aggregation and EFM, IEEE 802.3ad and ah.

Each of these methods assumes some standard physical layer technology as the underlying transport medium for the signal. These standards then combine multiple instances of the physical layer transport into a single logical circuit.

But, until now, all bonding solutions have suffered from all the known problems of single-pair DSL which are then multiplied by the use of multiple pairs:

1) Cross-interference between the loops has a severe impact on transmission performance compromising rate and reach.
2) Loop qualification times and cost are multiplied.
3) The low reliability inherent in single DSL lines is multiplied, resulting in an unreliable communication link which is unsuitable for premium business broadband services.
4) Introduction of high delay and long train-up times due to lack of coordination between pairs.

beam™ and physical layer bonding

This paper introduces Aktino, Inc.'s **beam**™ (**B**roadband **E**volution in **A**ccess over **M**ultipair) technology as a powerful new way of bonding copper lines. By performing bonding at the physical layer **beam**™ overcomes the problems of existing bonding methods and enables the delivery of high quality broadband services with unprecedented rate, reach and reliability across the entire subscriber customer base.

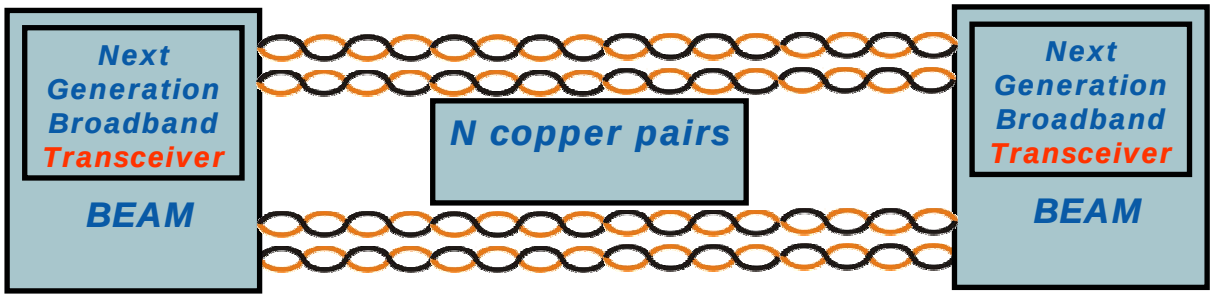
beam™ is different from the inverse multiplexing methods in a fundamental way. **beam**™ technology works at the physical layer itself and bonds the copper pairs into a single coordinated transmission medium that takes full advantage of joint signal processing and multi-input, multi-output (MIMO) techniques [see Figure below]. The methods used by **beam**™ have been studied and reported in the literature and are now being incorporated into Wireless LAN (IEEE 802.11 or WiFi) and wireless access (802.16/WiMax) standards. Wireline systems which use off-the-shelf silicon transceivers do not have access to the internal signal processing stages and intermediate signals that are required to implement true MIMO technology. In addition, only bonding at the physical layer can provide fast startup, low latency and the lowest framing overhead.

This document compares **beam**™ to other approaches to copper bonding. In particular, circuit layer bonding using off the shelf transceivers is shown to have significant deficiencies compared to **beam**™. Some of the main advantages of **beam**™ are detailed below:

- One-third to one-half the number of pairs is required to deliver the same bandwidth, enabling better utilization of existing infrastructure.
- Customer service denials due to lack of sufficient useable copper pairs are reduced substantially.
- The lower pair-count and higher bandwidth per pair provides a dramatic increase in the customer and footprint coverage.

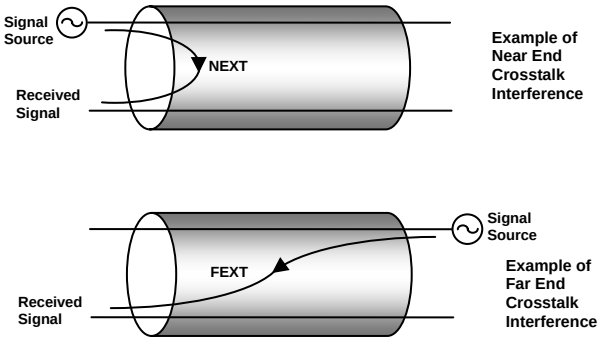
- Very high immunity to noise and line impairments ensures service approaching fiber-quality even in harsh environments, including the effect of extreme weather conditions on aerial cables.
- Provides fast recovery from pair failures or temporary outages.
- Compatibility with Dynamic Spectral Management techniques used to optimize residential ADSL performance from existing DSLAMs. This makes **beam**™ inherently more friendly to the large installed base of ADSL.
- Fully T1.417 compliant DMT line code with industry standard tone spacing and symbol rates.

All these advantages translate into increased customer rate, reach and reliability and therefore market share at lower cost. This in turn improves the service providers' revenue while decreasing Capex and Opex.



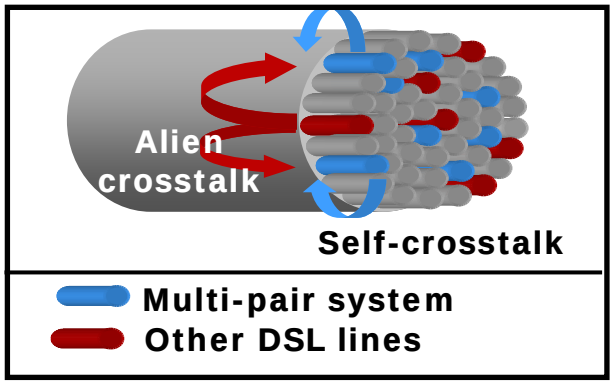
Crosstalk cancellation in beam™

For cable pair lengths of 9,000-12,000 feet the primary interference mechanism is Crosstalk, either NEXT or FEXT [see Figure]. This is Carrier Serving Area reach and also the reach that **beam**™ systems are optimized for.



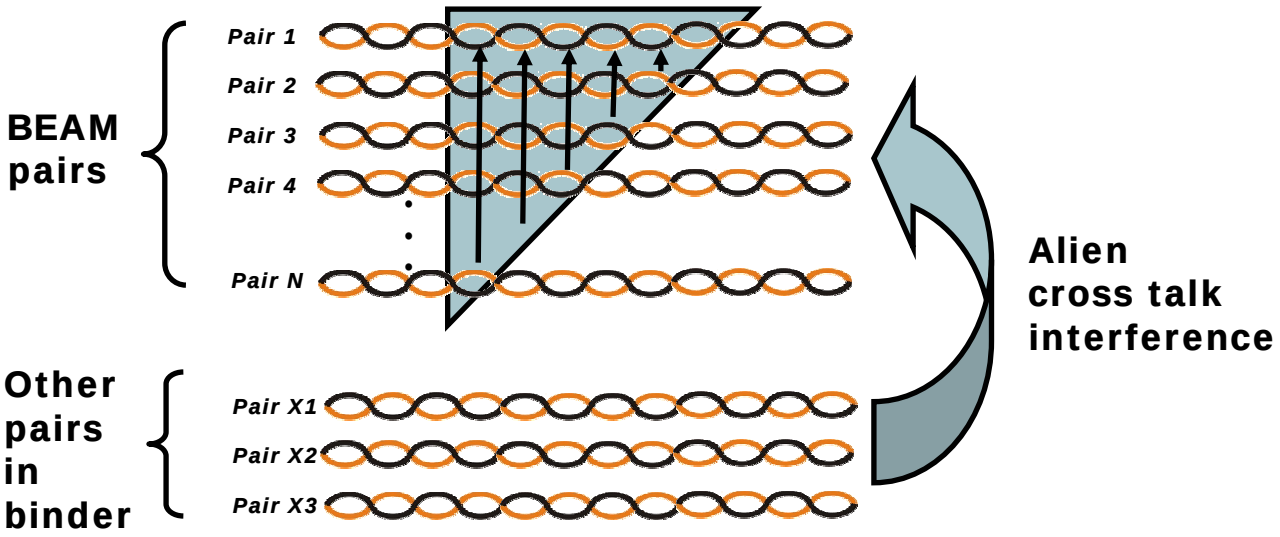
Both NEXT and FEXT crosstalk can be due to either "self" sources or "alien" sources. In the case of **beam**™ self-crosstalk is due to signals coupled from other **beam**™ pairs in the binder group [see Figure at right].

Alien crosstalk is due to signal pairs in the binder group which are not part of the **beam**™ pair set. Even advanced so-called Cross-Talk-Cancellation versions of existing systems are limited to attempts at reducing self-crosstalk. As such they do not help against alien crosstalk, most often the predominant interferer in the loops.



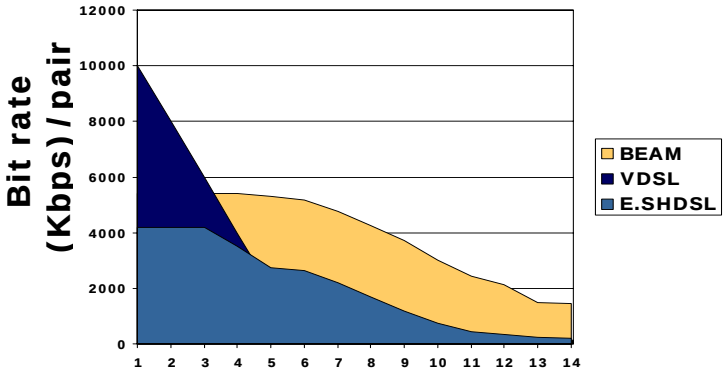
beam™ technology uses the FDM separation of DMT systems so that self-crosstalk is never created. Even more important, the knowledge of alien interferers is gained and refined through incremental correlation pair by pair so that more interference is removed with each pair processed. This results in very high interference cancellation when the number of pairs used by **beam**™ is 4 or higher. In fact, as more pairs are used by a **beam**™ system the performance per pair actually *increases,* as compared to other systems where per pair performance decreases with increased pairs.

This **beam**™ technique of sensing the interference signals in the binder group, specifically the alien-NEXT interferers, correlating these interference signals between each of the **beam**™ pairs in the binder and then eliminating the interferers on each pair in succession is illustrated in the Figure below. Existing systems using off-the-shelf silicon cannot eliminate this interference.



beam[TM] **bit rate performance**

All of these signal processing advances incorporated in **beam**[TM] ultimately result in significant performance gains when compared with logical bonded VDSL or SHDSL systems. The figure below shows the performance gain as a function of line length for **beam**[TM], VDSL and SHDSL systems all operating with multiple pairs. This chart is based on performance of 12 bonded copper pairs in a 25 Pair binder filled with HDSLx disturbers.



This diagram shows that **beam**[TM] performance exceeds logically bonded E.SHDSL or VDSL by a factor of 2 to 3 times in per pair bit rate performance over the range of 4-15 K Feet. This translates to dramatically greater footprint coverage, or significantly less copper pairs required for the same service. For carriers, this translates into a much larger percentage of served customers.

Conclusion

beam[TM] solves the problems that until now have been shared by all bonding solutions:

1) Cross-interference between the loops is significantly reduced enhancing rate and reach.
2) Loop qualification times are reduced or eliminated and cost is significantly lowered.
3) BER is enhanced through advanced symbol and line spanning coding providing for more robust transmission of data and voice.
4) Overhead is minimized through tight coordination at the physical layer and train-up time is drastically reduced compared to logical bonding schemes.

For all these reasons Aktino's **beam**[TM] technology is the next logical step in copper loop access.