Contract No.: 506790

U-BROAD

Ultra High Bit Rate over Copper Technologies for Broadband Multiservice Access

STREP

IST

Publishable final activity report

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Project coordinator organisation name: **Metalink Ltd**.

Revision [**01**]

Table of Contents

1. Project execution

1.1 Introduction

Current access network based on copper wires is one of the main existing infrastructures available for broadband connectivity. It enables most European citizens to receive broadband services. However, with ATM based ADSL/2+ networks capable for data speeds of up to 12Mbps/24Mbps the service is limited to delivery of voice and Internet together with very limited video capabilities. In order to enable true broadband connectivity capable to deliver full-scale rich content at an affordable cost there is a real need to enhance the future access network into higher bit rates and packet based transport enabling delivery of advanced services over Ethernet (and over DSL). This trend is materializing very fast in Asia Pacific markets, which currently lead the technological development, with successful examples of advanced services driven by this capability.

The significant interest in broadband services to home and Small Office/Home Office (SOHO) premises is strongly reflected on the standardization activity for equipment for the access network. Some of the influential bodies in this context are:

- IEEE802.3ah-Ethernet for the first mile. This subcommittee of IEEE standardizes Ethernet in the access network.
- ETSI committee TM06–Transmission and Multiplexing.
- ITU-T SG15-Q4-Transceivers for customer access and in-premises phone line networking systems on metallic pairs.

The main push for ultra high bit rates to date comes from the Pacific region. It is eminent to promote this technology with an eye on the **EU access networks,** since they have physical characteristics different than other (e.g., US and Japanese) access networks. Moreover we believe that the dense metropolitan areas in Europe provide a stronger economic motivation for this technology, compared to the US where population is more spread, and loop length is longer, with a typical customer service area of 3 km.
Ethernet is poised to become the technology of choice for **metropolitan networks**, as evidenced by the large installed base of 300 million Ethernet ports, the standardization of supporting protocols (e.g. 10GbE, RPR, EFM) and many network deployments. The appearance of IP/Ethernet based infrastructure in the public domain marked the beginning of a new era - **the era of all-Ethernet networks**. Using Ethernet in the first mile together with TDM over IP (TDMoIP) technology enables adding all the legacy traffic to the native Ethernet traffic. This combination offers a logical and affordable migration path to the future all-Ethernet networks, with no truck roll equipment replacements. Also, when considering a first mile technology, regardless of the backbone technology, we find that Ethernet integrated-access customer premises equipment (CPE) with an Ethernet aggregation device at the point-of-presence (POP) is much cheaper than native ATM/SDH at the customer premises and at the POP.
Therefore, the main objective of U-BROAD is to develop and integrate **advanced access technologies** for delivery of “true” broadband content over Ethernet based networks to the customer premises. It aims at **quadrupling** the total bandwidth available **over copper** to the end user. We focus in particular on the context of hybrid fiber-copper (Figure 1) architectures, like fiber to the basement (FTTB) or fiber to the curb/cabinet (FTTC) combined with a very-high bit rate digital subscriber line (VDSL) for the last segment, since this has attracted considerable interest in recent years as a promising low-overhead solution for broadband network access to businesses and residential premises. These architectures entail very short copper segments, typically few hundred meters – thus supporting transmission over up to 30 MHz.

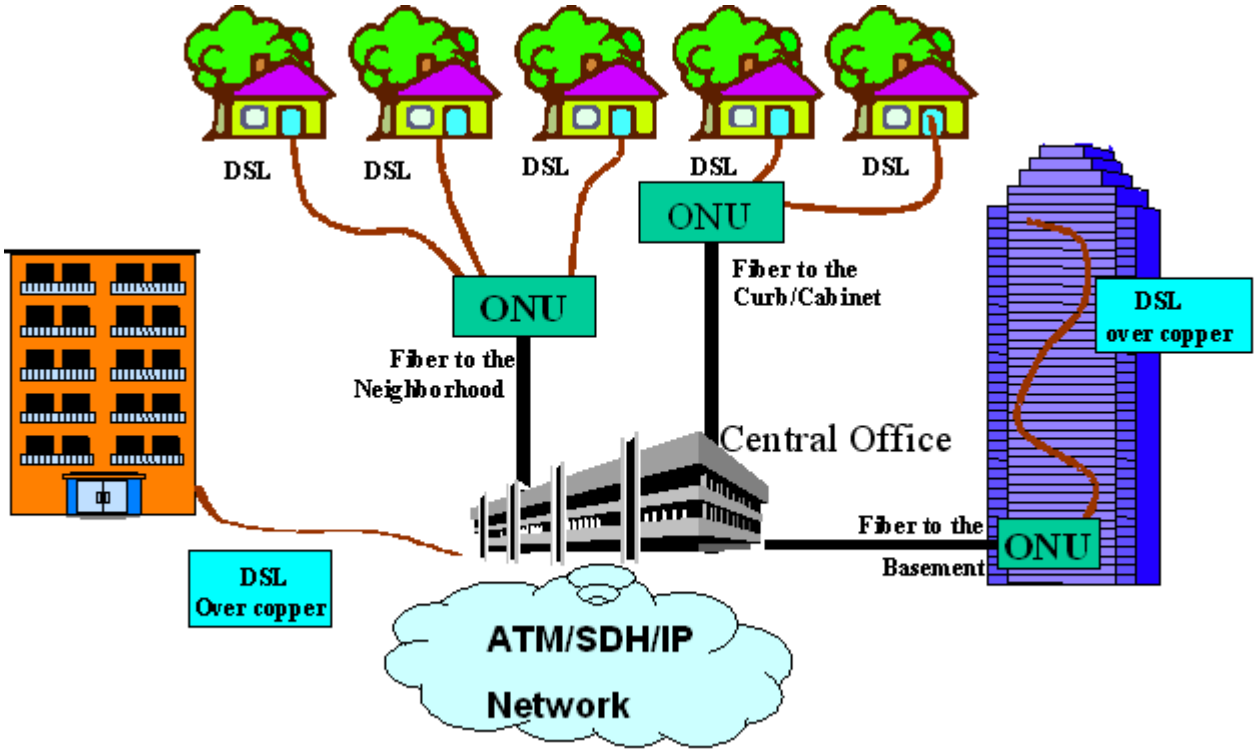

Figure 1: FTTx Topology

The following diagram in Figure 2 is a zoom into the system environment of U-BROAD technology. The solution constitutes a multi-service platform capable of supporting all traffic types (voice, data, and video) over DSL.

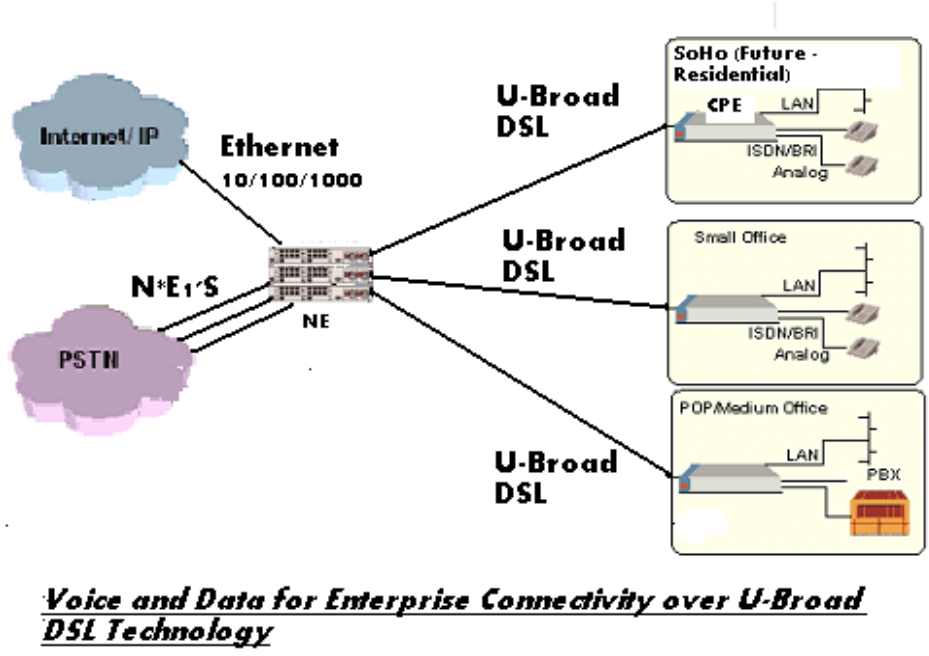

Figure 2: Network Interfaces

Our main objective encompasses several *Broadband for All* strategic objectives and was expressed as a list of Scientific and Technological objectives described in the following.

1.2. Project Objectives

The U-BROAD project is addressing the following IST strategic objectives for *Broadband for All:*

- Network technologies and architecture enabling broadband access to European users.
- Low cost access network equipment for legacy and new operating environments and services.
- Increased bandwidth capacity to the access network

1.3. Scientific and Technological Objectives

The main goal of U-BROAD is to achieve 100 Mbps over short distances (a few hundred meters). For such distances, VDSL is the pertinent high-speed transmission model. The key to achieve such rates is to extend the frequency usage of the copper wire from 12 MHz (VDSL) up to 30 MHz. However, this has several technological implications. Insertion loss (IL) decays more gracefully with frequency at these lengths, while far-end crosstalk (FEXT) becomes more prominent - e.g., at 75-150 meters, FEXT behaves in a way similar to near-end crosstalk (NEXT). For this reason, interference cancellation is more important for short loops than for long loops. In the downstream direction, interference cancellation exploits the fact that the Central Office (CO) has access to all pairs in a binder, and therefore can coordinate its transmissions towards the Customer Premises Equipment (CPEs). This coordinated (also known as *vectored*) multiple-input multiple-output (MIMO) transmission has recently emerged as an important research topic.

In view of the aforementioned considerations, U-BROAD has set the following objectives for its research and development:

- Development of a physical layer architecture and technology capable of providing spectrally compatible Fast Ethernet (100 Mbps) over existing copper cabling.
- Generic framework for bonding, coding and interference cancellation for information transmitted over single and multiple copper pairs.
- Crosstalk, and impulse noise modeling and characterization.
- Utilization of the “Ultra High Speed DSL” for connecting legacy, and next generation services to existing and future infrastructure.

1.4. Major project’s results

- Derived a theoretical bound on the number of samples required in blind separation using general cost functions to achieve a specified performance with a specified probability

- Put actual numbers on the capacity that can be expected from these short broadband copper loops, for both single-line and vectored transmission. This is the first time that the capacity of very short twisted copper channels is assessed based on measured data. Going beyond mean per-loop capacity, we have obtained hard data for minimum and maximum capacity (and thus capacity spread); plus estimates of the outage capacity.

- Derived algorithms for adaptive interference cancellation of forward (FEXT) crosstalk using limited feedback of the CPEs

- Were able to prove that downstream rates of 200 Mbps per pair are achievable on a coordinated binder for distance of 250m. This opens the possibility to Giga-Bit transmission over low number of pairs

- All results have been verified on measured binders of 28 channels. This is the first publicly available extensive study of multichannel techniques using real life measured data

- We have investigated the combination of shaped spectra and advanced coding, and shown that the reach can be improved significantly by a proper transmission shape design.

- Developed a prototype transceiver system that includes hw, sw and algorithms implementation. The results obtain in WP4, and that are summarized in D4.3 show that the UBROAD transceiver prototype has achieved 100 Mbps DS transmission up-to reach of 350m. Further more the results show that the transceiver can achieve rates of 100Mbps US transmission up-to 300m as well.

- The prototype transceiver which was developed is capable of up-to 100Mbps both in US and in DS at reach from 300m up to 1Km

- Created a significant list of journal and conference publications and contribution to standards as described in WP09

Figure 1: U-broad set-up

Figure 2 : Spools of copper wires

Figure 3 : Complete set-up

1.5. Participating Contractors

Partic. Role	Participant name	Participant short name	Country	Date enter project	Date exit project
CO	Metalink Ltd.	MTLK	Israel	M01	M24
CR	Rad Data Communications Ltd.	RAD	Israel	M01	M24
CR	France Telecom Sa	FTRD	France	M01	M24
CR	Hellenic Telecommunications Organization S.A.	OTE	Greece	M01	M24
CR	Telecommunication Systems Institute, Technical University Of Crete	TUC	Greece	M01	M24
CR	Bar Ilan University	BIU	Israel	M01	M24
CR	Delft University of Technology	DUT	The Netherlands	M01	M24
CR	OSM-DAN	OSM	Israel	M01	M24

Project coordinator name: **Mr. David Pereg**
email **david@metalinkBB.com**
Project coordinator organisation name: **Metalink Ltd**.

Project web site: www.metalinkbb.com/site/app/UBoard_summary.asp

2. Dissemination and use

2.1 publishable results

- Obtained VDSL2 crosstalk models derived from measured data for lengths between 75 and 590 meters and frequencies up to 30 MHz. The results indicate that the log-normal model (with a simple parametric law for the frequency-dependent mean) fits well up to 30 MHz. This further qualifies earlier log-normal modeling and validation results for bandwidths in the order of a few MHz. The fitted crosstalk power spectra are useful for modem design and simulation. Insertion loss, phase, and impulse response duration characteristics of the direct channels were also obtained. The results are summarized in a journal paper, to be published in *EURASIP Journal on Applied Signal Processing,* special issue on DSL
- Two algorithms for adaptive FEXT cancellation using precoding. The purpose of the first algorithm is to estimate, at the CO, the forward (FEXT) channels of all the crosstalk channels to all CPEs, without the use of training periods, but by using limited feedback from the CPEs to the CO. The precoder can be obtained by inverting the estimated crosstalk channel matrix. The purpose of the second algorithm is similar but avoids the matrix inversion step by directly designing and adapting the precoder such that forward (downstream) interference to each user CPE is minimized. This is an adaptive algorithm also relying on limited feedback of the received signal by each CPE, hence avoiding training overhead. The algorithms are developed by TUD. The results may be exploited by MTLK, in an implementation of vectored DSL (this is not planned as part of the UBROAD project). A software implementation of the results may be exploited as part of DSL network equipment. The algorithms will be published, making its use public domain. A further development may affect standardization, but this is not expected in the near future. Further research is needed to identify the preferred implementation details, and to derive alternative algorithms.
- Assessed single-pair and multi-pair VDSL2 channel capacities using the measured channel data. Key statistics (minimum, mean, maximum per-loop capacity) were obtained for both uncoordinated and vectored transmission, and the vectoring benefit was evaluated. The results provide useful bounds for developers and providers alike.

2.2 Dissemination of knowledge

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
01/05	Contribution to ITU standard committee	Research/industry	WW		MTLK
03/05	Conference ICASSP 2005	Research/industry	WW		BIU, TUC, TUD
03/05	Fast Net Future - exhibition	Industry	WW		MTLK
04/05	Journal paper, IEEE Signal Processing Letters	Research/industry	WW		TUC
06/05	Conference SPAWC 2005	Research/industry	WW		BIU, TUC
06/05	Conference Proc. of IEEE workshop on signal processing advances in wireless and wireline communications	Research/industry	WW		BIU, TUC

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
07/05	Journal paper, IEEE trans. on Comm	Research/industry	WW		BIU, TUC
08/05	Conference DySPAN 2005	Research/industry	WW		BIU
08/05	*Seminar talk BIU*	Research/industry	Israel		BIU
09/05	Journal paper, Eurasip Applied Signal Proc., special issue on DSL	Research/industry	WW		TUD
09/05	Journal paper, *IEEE Trans. Information Theory*	Research/industry	WW		TUC
12/05	*Seminar talk Ben Gurion university*	Research/industry	Israel		BIU
12/05	4th WSEAS International Conference On Information Security, Communications And Computers Iscoco 2005	Research/industry	WW		OTE
12/05	*Conference, Proc. IEEE CAMSAP 2005*	Research/industry	WW		TUC

List of Scientific Papers:

Refereed journal papers and book chapters

1. J. Louveaux and A.J. van der Veen, "Error-sign feedback as an alternative to pilots for the tracking of FEXT transfer functions in downstream VDSL", accepted, Eurasip J. Applied Signal Proc., special issue on DSL, Sep. 2005.
2. Amir Leshem and Alle-Jan van der Veen, "Blind source separation: The location of local minima in the case of finitely many samples", subm. to IEEE Tr. Signal Processing, Apr. 2005
3. J. Louveaux and A.J. van der Veen, "Adaptive DSL crosstalk precancellation design using low rate feedback from end users", subm. to IEEE Signal Processing Letters, Nov. 2005
4. J. Louveaux and A.J. van der Veen, "DSL crosstalk precanceller tracking using signed-error feedback", in preparation, to be submitted to IEEE Tr. Signal Processing, Jan. 2006
5. G. Leus and A.J. van der Veen, "Channel estimation", Chapter 5 in "Smart Antennas in Europe---State of the art", (T. Kaiser e.a., eds.), Eurasip book series, Hindawi, 2005, to appear.
6. G. Agapiou, T. Doukoglou, et. al. ''Throughput and Interference measurements in copper wires for xDSL type modem performance evaluation'', 2005
7. E. Karipidis, N. Sidiropoulos, A. Leshem, Li Y. "Experimental evaluation of the capacity of short VDSL2 loops". IEEE trans. on Comm. July 2005.
8. E. Karipidis, N. Sidiropoulos, A. Leshem, Li Y., R. Tarafi and M. Ouzzif. Statistical modeling of short VDSL2 loops up to 30 MHz. To appear in Eurasip Journal on Applied Signal processing – Special issue on DSL.
9. A. Leshem and Li Y. "A low complexity precoding scheme for transmission over copper". Revision submitted to IEEE trans. on signal processing July 2005.
10. A. Laufer, A. Leshem and H. Messer. "Game theoretic aspects of distributed spectral coordination". Submitted to IEEE Journal on Selected areas in communications. September 2005.
11. A. Leshem, E. Sayag and N. Sidiropoulos. "Quantization Effects on Linear Precoding for Multichannel DSL Transmission". Submitted IEEE Signal processing letters. November 2005.
12. N.D. Sidiropoulos, T.N. Davidson, Z-Q (Tom) Luo, "Transmit Beamforming for Physical Layer Multicasting", submitted to *IEEE Trans. on Signal Processing*
13. P. Liavas, ``On the sensitivity of a subptimal precoding scheme for frequency-selective block-based channels with respect to channel inaccuracies'', IEEE Trans. Information Theory, 51(9):3374—3381
14. A. Leshem and A-J. van der Veen. "Blind source separation: Performance with finitely many samples". Submitted to IEEE trans. on SP.

15. G. Latsoudas and N.D. Sidiropoulos, ``A Hybrid Probabilistic Data Association - Sphere Decoding Detector for Multiple - Input, Multiple - Output Systems", *IEEE Signal Processing Letters*, 12(4):309-312, Apr. 2005.
16. Z.-Q. Luo, N.D. Sidiropoulos, P. Tseng, S. Zhang, ``Approximation Bounds for Quadratic Optimization with Homogeneous Quadratic Constraints'', submitted to *SIAM Journal on Optimization*, Oct. 2005.
17. N.D. Sidiropoulos, Z.-Q. Luo, ``A Semidefinite Relaxation Approach to MIMO Detection for High-Order QAM Constellations'', submitted to *IEEE Signal Processing Letters*, Nov. 2005

Refereed conference papers

1. J. Louveaux and A.J. van der Veen, "Downstream VDSL channel tracking using limited feedback for crosstalk precompensated schemes", IEEE ICASSP, Philadelphia (PA), Mar 2005.
2. A. Laufer and A. Leshem. The prisoner's dilemma and distributed spectral coordination. Proc. of first IEEE conference on emerging techniques for dynamic spectrum access networks DYSPAN 2005. Baltimore, USA.
3. E. Karipidis, N. Sidiropoulos, A. Leshem and Li Y., "Capacity Statistics for Short DSL Loops from Measured 30 MHz Channel Data". Proc. of IEEE workshop on signal processing advances in wireless and wireline communications, New-York, June 2005
4. Li Youming and A. Leshem. "Efficient implementation of MMSE MIMO time domain equalizers". Proc. ICASSP 2005, Philadelphia, PA.
5. A. Leshem. On the capacity of multichannel DSL systems. Proc. IEEE workshop on Sensor arrays and Multichannel signal processing, Barcelona, Spain, July 2004.
6. Low complexity FEXT cancellation for VDSL. Proc. ICECS 2004, December 2004, Tel Aviv, Israel.
7. Low complexity linear precoding for transmission over copper. Submitted to IEEE trans. on SP. Review has been accepted. Very positive, and revision will be done in coming quarter.
8. E. Karipidis, N. Sidiropoulos, A. Leshem, Li Youming, "Capacity Statistics for Short DSL Loops from Measured 30 MHz Channel Data", in *Proc. IEEE SPAWC Workshop*, June 5-8, 2005, New York, NY, U.S.A
9. Metalink: G.Vdsl2: General Reference Model For Advance Coding. , ITU contribution : ITU SG15/Q4 - HH-048 (Jan 2006)
10. G. Agapiou et al., 4th WSEAS International Conference On Information Security, Communications And Computers Iscoco 2005, 16 - 18 December 2005
11. N.D. Sidiropoulos and T.N. Davidson, ``Broadcasting with Channel State Information", in *Proc. IEEE SAM 2004 Workshop*, July 18-21, 2004, Sitges, Barcelona, Spain
12. G. Latsoudas and N.D. Sidiropoulos, ``On the Performance of Certain Fixed - Complexity Multiuser Detectors in FEXT - limited Vectored DSL Systems", in *Proc. IEEE ICASSP* 2005, March 18-23, 2005, Philadelphia, PA, USA.
13. Liavas, ``On mean capacity degradation due to channel estimation errors", in *Proc. IEEE ICASSP* 2005, March 18-23, 2005, Philadelphia, PA, USA.
14. E. Karipidis, N. Sidiropoulos, A. Leshem, Li Youming, "Capacity Statistics for Short DSL Loops from Measured 30 MHz Channel Data", in *Proc. IEEE SPAWC Workshop*, June 5-8, 2005, New York City, NY, U.S.A.
15. E. Karipidis, N.D. Sidiropoulos, Z.-Q. Luo, "Transmit Beamforming to Multiple Co-channel Multicast Groups", in *Proc. IEEE CAMSAP 2005*, Dec. 13-15, 2005, Puerto Vallarta, Mexico, to appear.
16. E. Karipidis, N.D. Sidiropoulos, Z.-Q. (Tom) Luo, "Convex Transmit Beamforming For Downlink Multicasting to Multiple Co-channel Groups", in *Proc. IEEE ICASSP 2006*, May 14-19, 2006, Toulouse, France, to appear.
17. DSL Prime Article: http://www.isp-planet.com/cplanet/tech/2005/prime_letter_050603_vdsl.html