Multilink Transfer over Heterogeneous Networks

Dominik Kaspar, Audun F. Hansen, Carsten Griwodz {kaspar,audunh,griff}@simula.no

[simula . research laboratory]
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I. Motivation

In a world with numerous heterogeneous wireless technologies (e.g. WLAN, HSPA, WiMAX, etc.), devices such as cell phones and laptops are more and more often equipped with multiple communication interfaces. Motivated by this trend, major wireless providers, such as Telenor, are looking for solutions that can fully utilize multiple technologies when present (see Figure 1).

Related Work

For several years, related contributions have been proposed on many layers of the protocol stack, ranging from network-level multihoming (IP-in-IP tunneling) [3] over transport-layer protocol modifications, such as enabling SCTP to use multiple concurrent associations [2], to methods for application-layer striping [4].

However, to our best knowledge, most of the recent solutions for multilink support introduce modifications in end-host protocols (complicating widespread deployment), or they make very simple assumptions about the heterogeneity of wireless technologies (e.g. 30ms delay for both WLAN and UMTS [1]).

[1] Huang, C.-M., and Tsai, C.-H. WiMP-SCTP: Multi-path transmission using stream control transmission protocol (SCTP) in wireless networks. In *AINA Workshops (1)* (2007), pp. 209–214.

[2] Iyengar, J. R., Amer, P. D., and Stewart, R. Concurrent multipath transfer using SCTP multihoming over independent end-to-end paths. *IEEE/ACM Trans. Netw. 14*, 5 (2006).

[3] Phatak et al. IP-in-IP tunneling to enable the simultaneous use of multiple IP interfaces for network level connection striping. *Computer Networks* (2003).

[4] Wang, B., Wei, W., Guo, Z., and Towsley, D. Multipath live streaming via TCP: scheme, performance and benefits. In *ACM CoNEXT* (New York, NY, USA, 2007), ACM, pp. 1–12.

Potential Benefits of Multilink Striping

1. Increased throughput by link aggregation.
2. Additional fault tolerance by sending redundant data over independent links.
3. Increased connectivity through combination of several coverage areas.

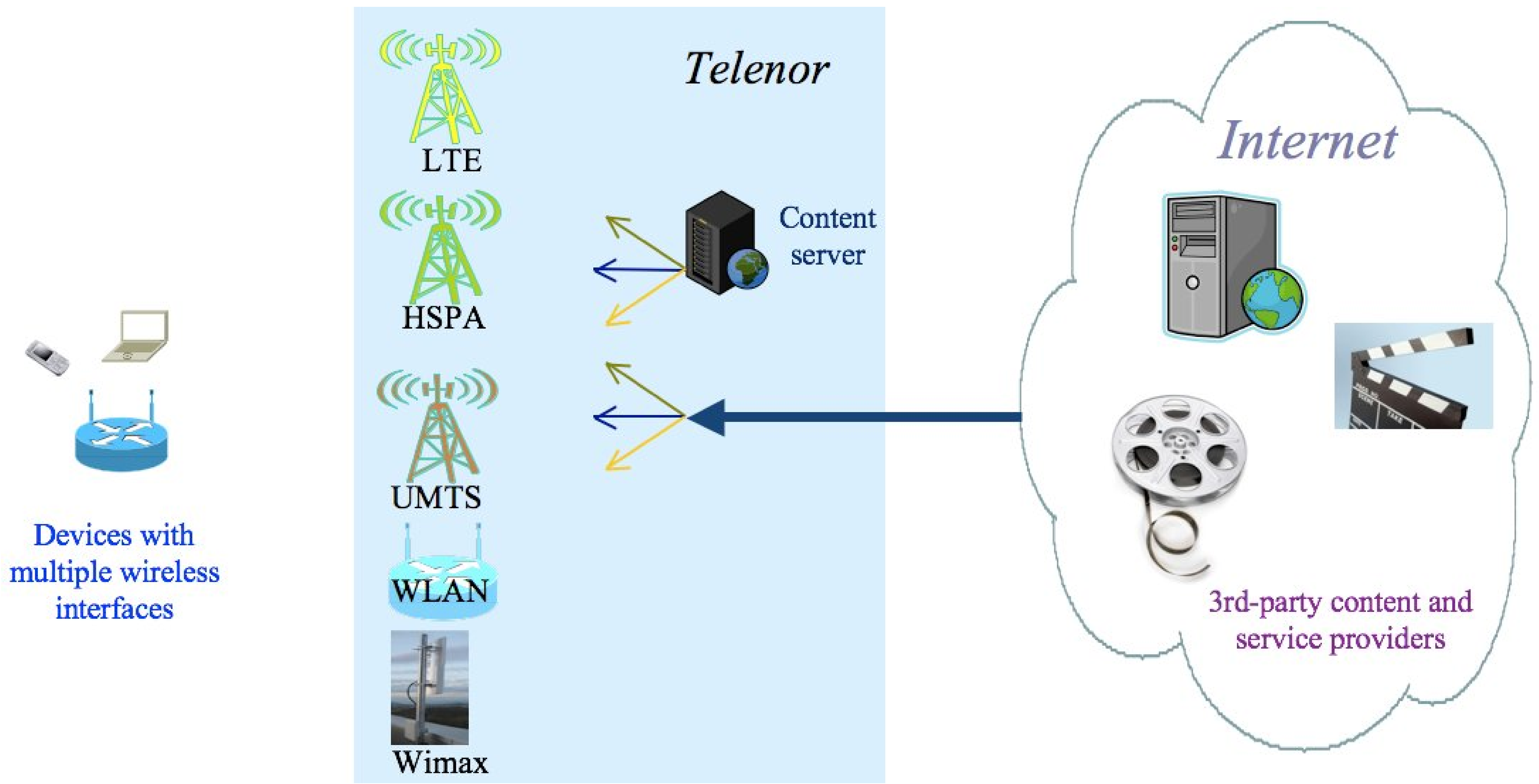

Figure 1: We envision a scenario where users of wireless and mobile terminals experience better quality by utilizing several links simultaneously. This should work even with 3rd-party content and services.

II. Results

For our studies on network striping, an experimental testbed has been set up, as shown in Figure 6. Both the server and the proxy machines are HP Compaq desktop computers with a 3GHz Intel Core2 Duo processor) and a high-speed Internet connection. As a client we use an HP Compaq 6715b laptop equipped with a Broadcom BCM4312 WLAN adapter and an AirCard 880U HSPA dongle manufactured by Sierra Wireless.

Link Heterogeneity

Figures 2 and 3 show the differences in round-trip time using HSDPA and WLAN technologies, while Figures 4 and 5 focus on packet loss. Numerical results on delay and throughput are shown in Table 1.

	packet loss	min.	max.	avg.	stdev.	Avg. TCP throughput	min.	max.
WLAN1	2.7%	2.2ms	5010ms	10.1ms	61.2ms	112 KB/s	98 KB/s	132 KB/s
WLAN2	1.5%	3.2ms	1807ms	11.2ms	59.0ms	178 KB/s	129 KB/s	312 KB/s
HSDPA	0.8%	67.5ms	1350ms	212ms	106ms	290 KB/s	276 KB/s	306 KB/s

Table 1: Round-trip time and throughput measurements over an HSDPA and two different WLAN connections. The RTTs were obtained using ICMP echo messages over a period of 24h to a close location. The throughput results have been obtained by downloading a 42 MB large file 10 times.

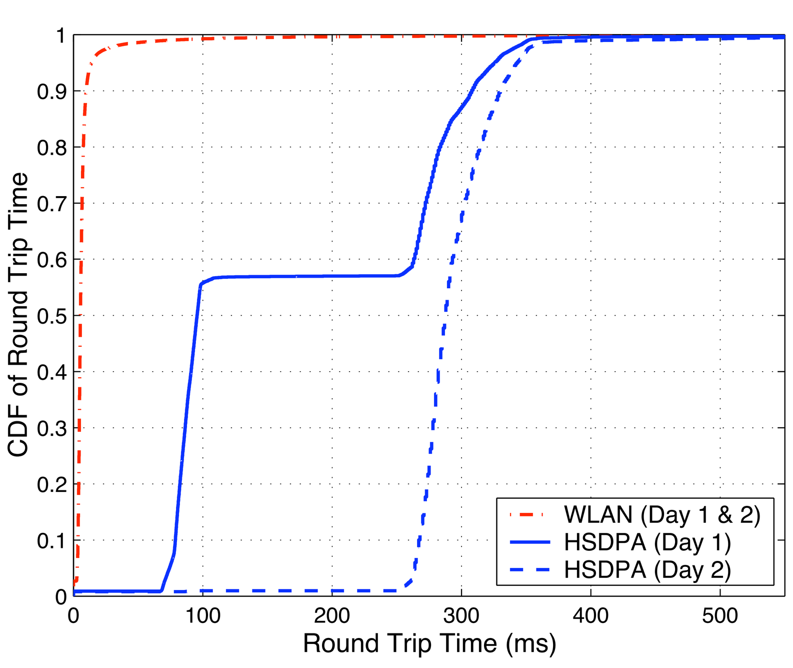

Figure 2: CDF of 86400 RTTs between client and server on two test days (the two WLAN links are not distinguishable at this scale).

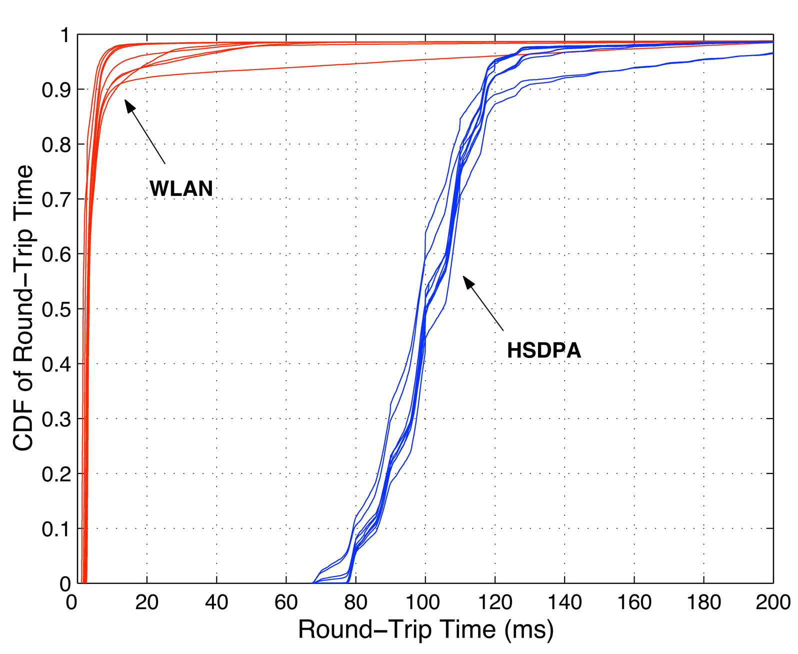

Figure 3: CDFs of 43200 concurrently measured RTTs for all hops on the path to the server, using Equal-Cost Multipath Routing (ECMP).

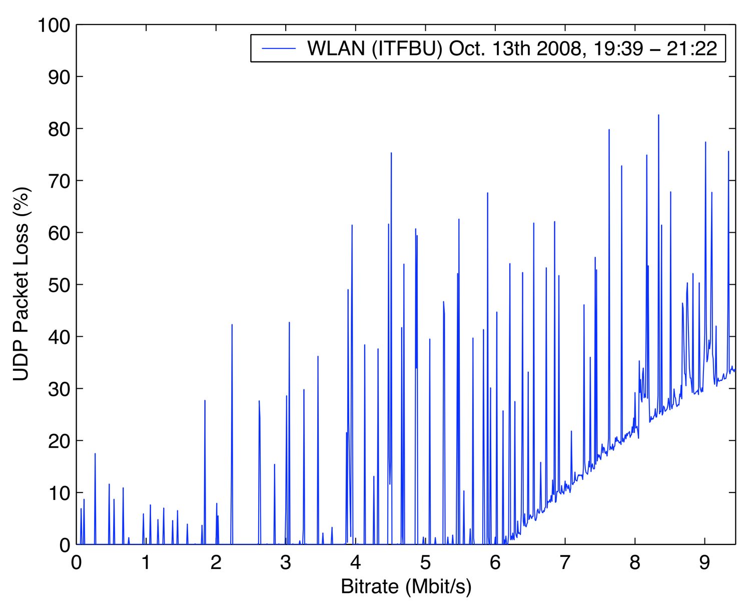

Figure 4: High variations of UDP packet loss at a constant bitrate over WLAN.

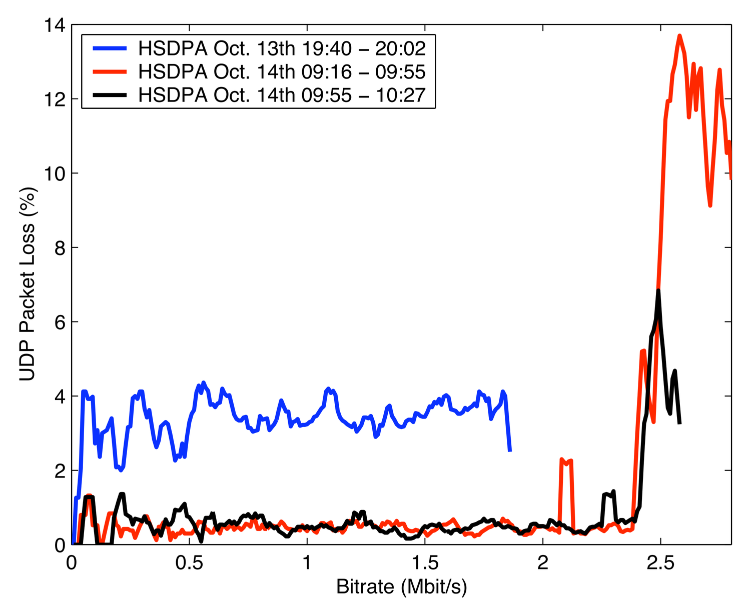

Figure 5: HSDPA has lower variations of packet loss than WLAN, but it depends on the time of day.

Observations

- Experiments verified our assumption that the first (wireless) hop is the throughput bottleneck and main contributor to delay and packet loss.
- We compared WLAN and HSDPA links and noticed significant differences in delay, which may result in severe transport-layer packet reordering.
- Links can vary rapidly over time. Therefore, path monitoring techniques might be required to cope with the dynamics of the wireless environment.

Conclusions Related to Prior Work

The large differences in minimum, maximum, and average RTT contradict frequently made assumptions about the characteristics of heterogeneous links, which are often modeled too evenly and not very realistically. The majority of existing solutions to network striping assume substantial modifications to protocols and end-hosts, which may hinder general deployment. The fact that most proposed solutions have only been tested in simulations, often based on very simple assumptions about heterogeneity, supports our skepticism to deployability.

III. Our Approach

In order to deploy multilink striping with minimal changes at the clients we pursue a proxy solution for connection splitting. We target a cross-layer solution that does not require any server-side modifications.

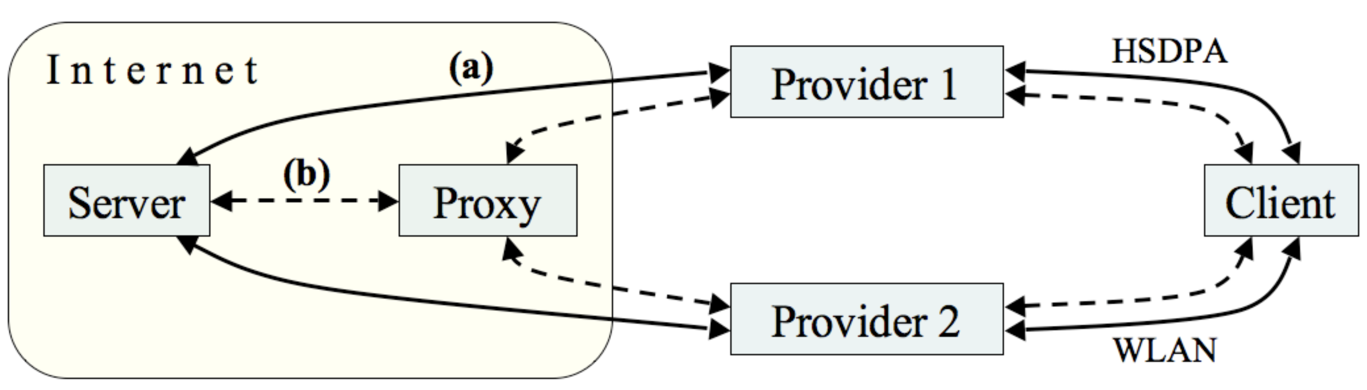

Figure 6: A client device with connections to a server over two access networks, with (a) direct connections and (b) a proxy solution.

Future Research Challenges

- An important research topic will be to assign an design the tasks given to the proxy.
- Scalability and resilience of the proxy are key design requirements.
- Path/connection monitoring (to allow precise link scheduling).
- Scheduling: a major difficulty will be to perform scheduled connection splitting at the proxy in order to improve throughput, reduce latency, and increase resilience.
- Energy optimization needs to be considered for battery-operated devices, because multiple links consume more energy than a single one.
- In a multilink scenario there exist many challenges on the Transport Layer, such as buffer management, reducing packet reordering, etc.
- Interaction between the proxy and servers.

Simula Research Laboratory / P.O.Box 134, 1325 Lysaker, Norway / Phone : +47 67 82 82 00 / Fax: +47 67 82 82 01 / www.simula.no