PCC Wireless IP - Optimizing Throughput and QoS over Fading Channels

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ABSTRACT

The Wireless IP project within the PCC program studies problems that are crucial in the evolution of UMTS towards high data rates, as well as in future 4G technologies aimed at rapidly mobile terminals. The goal is to attain higher througputs for packet data in particular in downlinks, without bandwidth expansion and while providing acceptable quality of service for various classes of traffic.

Two main techniques are investigated to accomplish this. First, the instantaneous channel quality of fast fading channels is measured and predicted for each user. These predictions are utilized in fast link adaptation and fast scheduling of different users who share a channel. Second, information is transferred between protocol layers to reduce inefficiencies. In particular, we study improvements of TCP that are aware of the state of wireless links, and that may be introduced in split connections. We also investigate the use in higher layers of soft information from the decoding in the link layer, possibly to create wireless-aware applications that use combined source and channel decoding.

INTRODUCTION

Our wireless systems are evolving rapidly and all traffic to mobile terminals will be IP-based end-to-end in a not too distant future. This raises many performance tradeoffs and design issues and we need to reexamine our approach to the design of such networks.

Systems for data communication are conceptually designed in multiple layers, from application down to the physical layer. Design and standardization is simplified when the layers are designed separately, with only limited interaction between them.

In the lower layers, the design principles are to a large extent based on averaging: Variations in channel quality are counteracted by coding and interleaving. CDMA is used partly to average out and reduce variations in the disturbance environment. Protocols are designed to control the long-term average throughput in a reasonable way.

Within the PCC Wireless IP project, we investigate the opposite to the principles described above. The reason is that large improvements in performance and quality of service could be gained in mobile wireless packet data systems by breaking with these traditions: Higher layers gain efficiency if information available at lower levels were made visible. The timevarying nature of mobile radio channels should furthermore be exploited, rather than averaged away[1].

Our intended target system is an asymmetric fourth generation packet data system that uses OFDM. The research is, however, of interest also for other types of systems such as further developments of UMTS towards higher data rates. Predictors for broadband channels are a crucial element of our philosophy. We develop such tools based on measurements of 5MHz UMTS channels.

The present paper gives a brief outline of our current research. More extensive presentations are given in [1], [2], [3], [4] and [5] at this conference. Additional details are found in the references available through our web site.

CHANNEL PREDICTION FOR USE IN FAST LINK ADAPTATION AND SCHEDULING

We exploit not only slow fading but also the *short-term fading* of channels to mobile users. The idea is that an

[1]This principle is to a limited extent being introduced in GSM via EDGE, which uses adaptive modulation to slowly adjust data rates to the channel conditions. We believe this method can be taken much further.

instantaneously good channel could enable the use of a very high data rate, if the packets used over the wireless link are not too long. At the other extreme, transmission near a fading dip is just a waste of resources. Furthermore, the differing fading for different mobile users will enable them to share the available bandwidth.

The task is then to optimize both quality of service and system throughput [2], [3], [7], [8]. Our proposed scheme is based on fast adaptive modulation and scheduling of the IP traffic that adapts to the short-term fading. We use predictions of the future channel quality for all active mobile terminals and are developing predictor algorithms for this purpose [9], [10], [11]. See Figure 1 for an illustration.

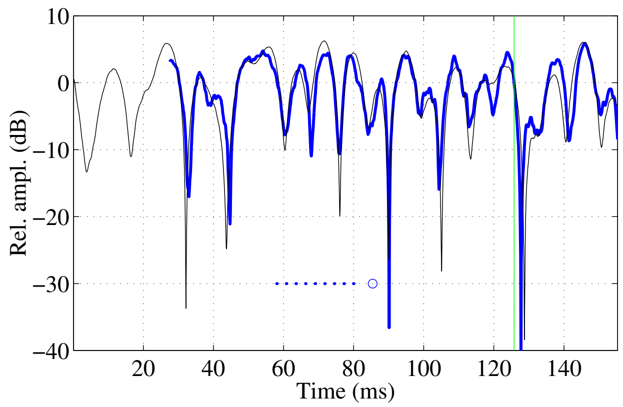

Figure 1: Typical long-term prediction result for one channel tap in a channel of bandwidth 5MHz at 1900 MHz. The prediction horizon is 5.5ms. The solid line is the prediction, overlaid on the true tap (thin line) which has here been estimated by least squares from measured channel sounding data. The illustrated predictor uses a FIR filter. The dots and circle illustrate the spacing of the FIR filter taps and the predicted point, respectively.

The traffic to different users is scheduled for short time intervals ahead, so that their total satisfaction is maximized. The scheduler controls the outflow from queues, one for each user and each traffic class, see Figure 2. Transmissions that require low delay, such as speech, will of course be given high priority.

Channels of desired quality are not always available and channel prediction will sometimes fail. Coding must therefore be used to increase robustness. Turbo coding is one powerful alternative [1], [12], but there are other techniques that introduce redundancy *only when required*. We investigate hybrid type-II ARQ schemes in combination with the predictive scheduling [3], [6]. Hybrid type-II ARQ uses incremental redundancy. It first sends an uncoded transmission and then transmits additional redundant symbols if the previous transmissions were unsuccessful [13].

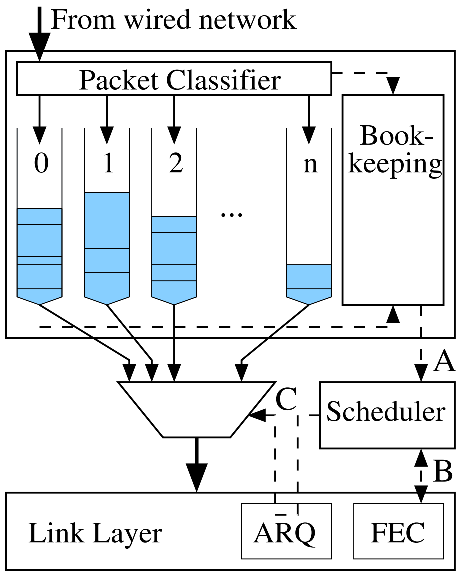

Figure 2: Schematic of the buffer and its queues, and how they interconnect to the scheduler and link layer. The packets arrive at the top and are inserted into their respective queues, restoring order among occasionally arriving out-of-order packets. The buffer regularly submits a status report (A) to the scheduler, containing info about the priorities, the size of the queues, and the required link service, some of which is also passed to the link layer (B). The scheduling decision (C) is updated by the link layer ARQ, and is then used to drain the queues.

IMPROVED TRANSPORT LAYER PROTOCOLS

Sometimes, perhaps due to shadow fading, both the scheduling and coding will fail, and packets have to be retransmitted. Here, the presently used TCP/IP protocols are inefficient when used over fading radio channels with time-varying quality. Packet losses due to channel conditions should not be counteracted as if their cause was congestion in a fixed network.

We study various end-to-end and split-connection modifications to TCP that optimize the IP traffic over fading links [4]. One type, a double split connection, is illustrated by Figure 3.

These algoritms control the input to the queues in Figure 2. They constitute a flow control system that works on a time-scale at least an order of magnitude slower than that of the scheduling algorithm.

TCP protocols operating in the wired/wireless interface and over the wireless link can be improved by taking information from lower layers into account. Other urgent modifications are methods for estimating the available bandwidth that are not degraded by packet losses and time-varying delays introduced by fading in the wireless link. One such modification that promises a large performance improvement over wireless links and that needs to be im-

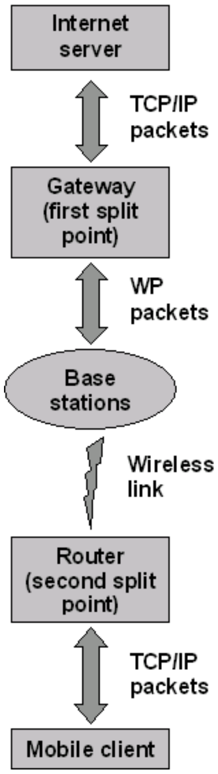

Figure 3: A double-split connection of TCP. At a gateway, TCP packets are converted to a wireless protocol (WP) optimized for wireless links, which might be a variant of TCP. The packets are transferred to the scheduling queues, transmitted and converted back to TCP at the other split point located in the wireless device. Thus, no changes need to be introduced at the TCP end-points. TCP applications that cannot handle semantic breakage caused by the split will not have their packets converted to WP but will just use header compression.

plemented on the sender-side only is TCP Westwood [14]. It has been inspired by recent control theoretical insights into the nature of TCP and packet data flow control algorithms in general [15].

USE OF SOFT INFORMATION IN IP-BASED WIRELESS NETWORKS

The proposed processing creates information, such as soft decoded symbols or MAP estimates, that is not available to higher layers in present systems. We propose and investigate the use of such information from the link layer in higher layers and in applications [5].

To give just a simple example: If a single bit error occurs that is not recoverable by the coding, the whole packet must normally be re-transmitted, with a considerable delay. If the application on the wireless device could use a MAP estimate of the uncertain bit for example to recreate a near-perfect image or sound, the need for retransmissions would be reduced drastically.

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