Cross Layer Protocols Design for Next Generation Wireless Systems

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***Abstract*— This thesis deals with the application of the cross layer principle to design protocols allowing an effective quality to the communications supported by next wireless systems. In particular, we have focused on the interactions among physical, MAC, LLC and Network layers aiming at optimizing the power consumption, the error rate, the link throughput, the end-to-end efficiency and the overall delay. We apply this approach to an heterogeneous network composed of different air interfaces all relying on the packet switched technology. The analytical and numerical results highlight a remarkable gain attained by the proposed techniques with regard to the single layer aware existing protocols.**

I. Introduction

Despite the wide success of 2G personal communication systems in the last decade, however the diffusion of 3G systems has met with a progressive resistance, but the number of mobile or Internet subscribers has been growing up at a considerable rate highlighting the market interest [1]. The demand for high bandwidth web-oriented applications endowed with novel mobile interaction paradigms has to be satisfied to face this lack. It is likely that an effective proposal might not leave the QoS management apart but faces it by increasing on bandwidth offering, enhancing in the error detection and correction fields, matching of effective throughput and lowering of the overall delivering delay.

The application mobility inherently involves wireless communications that have peculiarities different from conventional wireline transmissions. In particular, the wireless channel has short-term (or small-scale) memory due to multipath [2] and a long-term contribution depending on the user locations and the interference levels [3], both causing bursts of errors to occur during which packets cannot be successfully transmitted on the link, thus making the channels state varying.

To improve the ovearll network efficiency, the protocol design strictly based on the ISO/OSI *transparency* principle seems to be unaffective because the optimization of each layer independently from the others often leads to a suboptimal overall performance. A promising research avenues for such an important topic is undoubtedly represented by the so called *cross-layer* networking [4], where basically the Physical and Medium Access Control (MAC) layers knowledge of the wireless medium is shared with higher layers. The generalization of this idea is the provisioning of an *impedance matching* of the instantaneous communication status with the user capacity requirements. This status involves not only the radio channel conditions but also the medium features in terms of collision and network congestion as.

By resorting to the above considerations, our research applies the cross-layer principle to manage several communication requirements over a wireless infrastructure. We first focus in Chapter I on the problem of the link throughput maximization by proposing two different approaches, both of them belonging to the the class of Hybrid-ARQ (H-ARQ) schemes and explicitly conceived for the case of reliable services. Besides, we provides an insight on the relationship between Logical Link Control (LLC) and Transport layers with the aim of maximizing the effective throughput by avoiding the impairments of the congestion control algorithm.

Then, in Chapter II the interactions between LLC and MAC layers are investigated, proposing several methods able to match the channel variations and the user mobility based on the Adaptive Link Control (ALC) approach.

As far as the problem of radio resources allocation, we propose in Chapter III an hybrid Dynamic Bandwidth Allocation (DBA) technique, taking advantage of a proper statistical traffic modeling to predict future bandwidth requests. This implies a strict interaction between LLC and MAC layers, as the scheduling policies are influenced by the access scheme and vice versa.

Finally, Chapter IV is devoted to the investigation about power efficient routing algorithms aware of the packet transmission outcome, hence, tightly connecting the Transport and MAC layers. In particular, we introduce several optimizations to the Terminodes project [5] by means of a generalized path metric and taking into account MAC layer retransmissions.

II. Soft Combining techniques

In this Chapter, we propose two techniques,i.e. Soft Input Combining (SIC) and Soft Output Combining (SOC), belonging to the the class of Hybrid-ARQ (H-ARQ) schemes and both representing an improvement of the basic *Chase Combining*.

We firstly derive a simple though accurate channel model in order to highlight the impact of mobility on received signal quality. Then, the SCs techniques are introduced together with providing an analytical framework, a proposed case study and

the related simulation results together with investigating the impact on the congestion control algorithms.

III. Adaptive Link Control algorithms

Several enhanced access schemes have been recently proposed IMT2000, as 1xEVDO for cdma2000 standard [6] and High Speed Downlink Packet Access (HSDPA)for 3GPP [7]. Recent research [8], [9] has demonstrated that adaptation can be performed at all layers of the protocol stack to face the dynamics of wireless channels and to improve the link efficiency, in particular, involving the MAC layer packet scheduling and the LLC layer packet transmission format. Briefly, the proposed scheme, referred as Acknowledgment Driven (AD) policy, performs the channel monitoring by means of the receiver feedbacks and, hence, the best transmission format - i.e., Modulation and Coding Scheme (MCS) - is selected in order to optimize the system performance, thus generalizing the *Incremental Redundancy* approach.

This technique belonging to the class of proactive algorithms, it can outperform the basic scheme where a static rate allocation is adopted, especially for high loaded links and bursty traffics. The achieved gain allows to maximize the link-to-link throughput together with lowering queuing delay or increasing the number of active connections.

After describing the the AD algorithms, it is provided the optimal rule to track channel capacity variations by means of the received acknowledgments. Besides, the performance for a a generic number of MCSs are analytically derived, with particular regard to the case of two MCs. Finally, ALC techniques will be applied both to a HSDPA and TEDS systems.

IV. Dynamic Bandwidth Allocation techniques

The future communications development involves the realization of an *universal* network in the sense that infrastructures, devices and applications might be virtually *transparent* according to the final user point of view. Besides, to control the deployment and maintenance costs it will be mandatory the exploitation of the packet switched.

Satellites networks seem to be the proper candidates to provide such high quality IP services and to match the different network segments integration principle of the 4G systems. However, efficient bandwidth allocation algorithms have to be developed since this is an extremely valuable resource. To this end, an hybrid approach, avoiding the impairments of both fixed and dynamic bandwidth allocation schemes, has been proposed. Moreover, to adapt the transmission rate to the source rate a prediction of the resource needs has to be considered; in particular, the statistical properties of IP traffic has to be properly investigated in Appendix to obtain a better QoS for the time-sensitive traffic by means of a proactive capacity request control.

In this Chapter, we firstly characterize the services supported by the telecommunications network providing a Self-Similar (SS) traffic model. This allow us to propose an effective traffic prediction algorithm, belonging to the Maximum Likelihood (ML) class. Then it is applied to an efficient DBA scheme that is introduced and validated for a practical case study, represented by the Digital Video Broadcasting Return Channel Satellite (DVB-RCS) system [10], endowed with a *Diffentiated Services* (*DiffServ*) traffic management scheme.

V. Routing protocols for Ad Hoc networks

The integration of different systems relies on the the concept of a network architecture released from any kind of infrastructure. At present the *Ad Hoc* networks [11] paradigm seems to effectively match these requirements, since efficient, dynamic and reliable communications could be quickly set up through a self-organizing and infrastructureless set of nodes, especially by resorting to a multi-layer joint optimization.

With particular reference to the routing topic, novel distributed and reactive protocols are needed, since the traditional wired networks approaches present several drawbacks. Besides, these protocols are requested to be scalability and energy consumption aware.

Energy aware routing protocols that can be found in the literature neither are related with the protocols under standardization (*DSR*, *AODV*, *OLSR*, *TBRPF*) [12], nor with the wide area Ad Hoc networks projects, as *GPSR*, *Grid*, *Terminodes*.

Our proposal makes up for these shortcomings by introducing several routing metrics more complex than the elementary minimum distance metric adopted in the advanced release of the Terminodes Project. In addition to this, we present an integration between the Network and the MAC layers to attain a better efficiency in accordance to the cross-layer approach.

Moreover, the effectiveness of our protocol has been tested in a complex scenario composed of zones with high density and low mobility nodes, connected by zones with a short number of nodes moving very fast.

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