A Cross-Layer Design Framework using Functional Components

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ABSTRACT

We present a framework for cross-layer optimization in small, resource-constrained wireless communication systems that require a high degree of optimization. We argue that often these systems allow for a departure from conventional OSI network stack design principles, opening up broad opportunities for optimizations. We examine these new opportunities and propose a design strategy to take advantage of them. Simulation results are presented in support of our design framework proposal and as motivation for future work in this important area.

Keywords: AODV; Cross-Layer Design; DSR; JiST; Networking; SWANS; ZRP

INTRODUCTION

Since the 1970s, computer network protocol stacks have been implemented according to layered architectures based on the famous OSI Model. Layered architectures have been successful because they force protocol software to be highly modular, leading to such desirable properties as good flexibility, maintainability, and reusability. However, recent network types, particularly digital wireless networks, push to improve protocol efficiency beyond what is currently available.

Increasingly, researchers are exploring alternative protocol stack designs that may improve performance, typically referring to them as cross-layer designs or designs incorporating cross-layer optimization. While a layered architecture provides well structured software that is simple and easy to maintain, it also prevents most data sharing between layers, obstructing potential methods of improving performance. The cross-layer design philosophy asserts that if more information is shared between layers, performance improvements can be achieved.
One popular application of cross-layer optimizations is OFDM/MIMO networks. In these systems, complex decisions such as channel and rate selection must be made that affect the throughput and power consumption of the network. Sharing data between layers gives an opportunity for improved performance, since these decisions can be made using more information. Many such efforts involve sharing of data between the closely related link layer and physical layer (Cui & Goldsmith, 2005; Huang & Letaief, 2005; Kwon et al., 2005; Li, Thu, Xiao, & Liu, 2005; Song & Li, 2005). A summary of OFDM cross-layer designs is given by Bohge, Gross, Wolisz, and Meyer (2007).

Wireless video transmission, because it is so bandwidth intensive, is also a good candidate for optimization, including cross-layer design. For example, van der Schaar, Turaga, and Wong (2006) feed data from the application layer pertaining to the content of the video into a classifier that has been taught to identify types of video and adjust network stack parameters accordingly to optimize performance.

These cross-layer protocol stack designs can be either evolutionary or revolutionary (Gavrilovska, 2006). Revolutionary are those that discard the existing protocols and layered architecture in favor of an entirely new design (Akjildiz, Vuran, & Akan, 2006). Research in this direction has been limited, due to the fact that resultant systems may be incompatible with existing infrastructure and the long history of computer networking has shown that a layered architecture is the most appropriate for protocol software. Evolutionary designs maintain existing designs and modify them in various ways to improve performance. Such designs can be backwards compatible with existing systems, but since by definition there is less freedom in the design, the potential for gains is not as large. Regardless, a fair amount of research has been devoted to this direction (Su & Lim, 2006; Raisinghani & Iyer, 2006).

Among evolutionary designs there are varying degrees of complexity and departure from the layered design. Earliest designs add coupling between layers that otherwise does not exist in the layered architecture, to allow a layer to get information about the state of another layer that will help it make better decisions to improve performance. This is perhaps the simplest cross-layer design, although, depending on the amount of coupling, it can get quite complex and unmaintainable. However, it arises naturally from the way someone would typically approach cross-layer design: examine the various protocols in the stack, take note of when and where it would be beneficial for one protocol to have knowledge of the state of another, and pass the information along, while ignoring the layering rules. This approach is thus very design friendly, although it requires a good working knowledge of multiple protocols. Because of this, it has been most commonly applied to Physical–MAC layer information sharing, since these two layers are typically designed together (Shakkotai, Rappaport, & Karlsson, 2003).

A more sophisticated evolutionary approach is to modify the architecture to support cross-layer information sharing. This can be done either by creating a generic interface with which layers can communicate with each other (Wang & Abu-Rgheff, 2003) or by introducing one or more new components in the architecture to facilitate data sharing. Of the two, creating a new component has the benefit of minimizing changes to existing protocol software and maintaining component modularity. New components in the architecture can be either active or passive, the latter exemplified best by a global storage component in which the layers can deposit and retrieve information (Borgia, Conti, & Delmastro, 2006). Active components gather information from layers and use it to control the behavior of the protocols to optimize performance.

**Contribution**

In this article, we propose a new approach to cross-layer network design driven by the need for optimization in mobile wireless networks and other resource-constrained networks. This approach is justified based on the unique circumstances under which these systems op-
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