Adaptivity With and Within Physical Layer for Pervasive Computing

TÜLAY ADALI
Department of CSEE
University of Maryland Baltimore County
Baltimore, MD 21250
adali@umbc.edu

Though slightly dated, the report of the 1998 NSF workshop on "Tetherless T3 and Beyond" [1] still deserves attention. The report includes couple of key observations that are highly relevant for the discussions of the workshop on "Context-Aware Mobile Database Management". In particular, the main conclusion of the 1998 workshop needs to be underlined and is yet to be implemented. The summary statement of the workshop report said:

> Significant advances in basic research to provide a foundation for designing high information-capacity wireless communication systems for full mobility will require synergistic, multidisciplinary research efforts encompassing a breadth of communications functions from the physical through application layers. Such research would be expected to lead to breakthroughs enabling future wireless networks to be flexible, scalable to huge numbers of users, able to provide location information of mobile users on a global scale, eavesdropper proof, coordinated with wireline and other networks, dynamically adaptable with demand, and able to provide guaranteed service while accommodating mixed traffic representing varied applications.

As for the future wireless systems, all layers of the communications protocol are looking at solutions that are highly adaptable, able to track the changes in the channel and traffic conditions and switch between different network interfaces, it is critical for them to fully communicate among themselves to avoid any potential conflicts and to jointly optimize the performance. This necessitates full communication and cooperation among the physical, network, and application layers. This need for full interaction has finally been accepted in a certain part of the research community and a number of projects and workshops are aimed at increasing the collaboration among the communications layers (e.g., the 2001 "NSF/ONR Workshop on Cross-Layer Design in Adaptive Ad Hoc Networks," [3]). However, the area is still in its infancy and the adaptive interaction strategies are mostly constrained to neighboring layers. I am hoping that the discussions of the workshop on "Context-Aware Mobile Database Management" will help determine directions for research beyond this limited interaction resulting in a truly unified view of the wireless systems.

Among the numerous proposed solutions for the next generation wireless systems, spread spectrum (SS) and Code Division Multiple Access (CDMA) methods have received particular attention, and have largely benefited from many years of active exploration in military labs (see e.g., [2]). However, when the transceiver has to adapt not only to time-varying channel characteristics but to inherently different channel responses, data rates and transmission bands as well, adaptivity of the basic transceiver structure becomes of utmost importance. The communication system should be able to track variations in the channel response with reliable equalization and signaling during the transmissions, and when the network connection is switched (e.g., from satellite communications to a wireless local area network (LAN)), should be able to adapt its transmission scheme; as well as corresponding equalization, to the new environment effectively, and with a tolerable delay during the switch from one network to the other.

Multi-carrier modulation (MCM) is a very attractive candidate for satisfying the high demand on adaptability in the transmission and its flexible structure can also be used for optimization with network and application protocols. MCM is based on the principle of creating multiple orthogonal subchannels by dividing the data stream into multiple parallel streams, each of which has a much lower rate, and using these substreams to modulate multiple carriers. The biggest strengths of MCM are its versatility, rate adaptability, and flexibility in coping with a wide range of channel environments by adjusting the energy and constellation size of each carrier. On the wired side, an implementation of MCM, the discrete multi-tone (DMT) system is successfully used for ADSL and is the strongest candidate for VDSL. Its wireless implementation, orthogonal frequency division multiplexing (OFDM) has been adopted for several television and radio broadcast applications including the European digital broadcast television standard. OFDM is also used in several fixed wireless systems and wireless LAN products. Finally, multicarrier CDMA is a multiple access scheme based on combination of OFDM and code division and a number of its varieties exist [4] and have been proposed as attractive alternatives for the future wireless systems.

One of the biggest challenges in the ad-hoc networking environment is the characterization of the physical channel. The high degree of variability of the wireless channel (also augmented by the fact that it can vary abruptly when the network connections are switched) distinguish it from other channels, such as the wireline and the optical channel where, for most part, the rate of change is very moderate. What is more, these channels, especially the wireline channel, have now been widely researched and successfully modeled. In wireless, with the given new bands and traffic requirements, there is still much need for basic research for their characterization, and typical channel models for wireless such as the Rayleigh fading channel model (see e.g., [7]) are inaccurate for broadband signals that fade in a Ricean or lognormal fashion. Hence, the development of flexible transceivers, e.g., those promised by the MCM technology, should be coupled to development of accurate channel models for the wireless medium. They will be instrumental not only in establishing network protocols and variables for optimized performance in the wireless medium but in determining effective upper layer functions such as cache sizes and strategies as well.

MCM is a relatively new technology, and its implementation in the now well-defined wireline environment (e.g., our recent work with Nortel Networks [5, 6]) made it clear that even problems such as equalization (regarded as effective channel impulse response shortening in the implementation of MCM with a cyclic prefix) are not straightforward for this new technology. Also, there are additional considerations such as the need to reduce the peak-to-average (PAR) ratio (because the superposition of many carriers in multitone leads to a Gaussian-like density with a high PAR). The PAR reduction is especially critical making it difficult to operate in the linear region of the amplifiers. However, it is important not to look at these issues as independent considerations in the physical layer. Since, most of these issues require "adaptive" solutions as well, when investigating solutions, it is important to investigate how their adaptivity can be combined with other considerations and the performance of the wireless systems can be jointly optimized.

References

[1] M. Dunham *et al.* (editors), Proc. of NSF Workshop on "Tetherless T3 and Beyond," Denver, CO, Nov. 1998.

[2] Proc. IEEE Signal Processing Workshop on Signal Processing Advances in Wireless Communications, March 2001, Taoyuan, Taiwan, R.O.C.

[3] NSF/ONR Workshop on "Cross-Layer Design in Adaptive Ad Hoc Networks: From Signal Processing to Global Networking," 2001, Cornell University Ithaca, NY, `http://www-monet.cs.uiuc.edu/workshop/adhoc/`

[4] S. Hara and R. Prasad, "Overview of multicarrier CDMA," *IEEE Comm. Mag.*, pp. 126–133, Dec. 1997.

[5] B. Wang and T. Adalı, "A weighted frequency-domain least squares approach for equalization and noise suppression in discrete multitone systems," in *Proc. IEEE Int. Conf. Comm.*, June 2000, New Orleans, LA.

[6] B. Wang and T. Adalı, "A frequency domain training approach for equalization and noise suppression in discrete multitone systems", *Signal Processing*, in review.

[7] T. Adalı, S. H. Ardalan, and A. S. Sadri, "Multichannel general order FTF algorithm and its application to the equalization of mobile communication channels," in *Proc. IEEE Int. Conf. Acoust., Speech, Signal Processing (ICASSP)*, San Francisco, CA, vol. 4, March 1992, pp. 517–520.