ADVANCED MULTIMEDIA COMMUNICATION SYSTEMS

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A fundamental challenge for present and future communication systems is the ability to transport multimedia content to a wide variety of terminals (TV, PC, PDA, cell phone), over a variety of networks (broadcast, Internet, GPRS, CDMA), at different channel conditions (congestion, high bit-error), different bitrates and different quality-of-service. This challenge leads to a number of technical problems that yet needs to be solved in a number of disciplines, including digital signal processing, telecommunications, networking, antennas and propagation and electronic circuit design. In the following, we first identify these technical problems and then propose solutions to overcome them.

Advanced communications systems may need to process multimedia content, at the server, at the terminals and/or in the network. Digital multimedia (includes video, audio, speech and graphics) processing technologies are required to pre-process, encode, stream, transcode, and post-process (to conceal errors) digital content for transmission, as well as analysis, synthesis and summarization of digital content at the production stage. Another important signal processing problem is secure access and digital rights management.

As packet networks are making the transition from data communications to time-sensitive multimedia communications, delay and quality of service becomes important performance parameters. Achieving the optimum performance often requires interaction between signal processing (source/channel coding) and protocol design. One of the most challenging problems is multicast multimedia communications that require reliable delivery of data to all participants who have different terminals and bandwidths.

Mobile wireless communications services must serve multimedia traffic to both outdoor and indoor environments. It is of paramount importance to be able to characterize these channels accurately. In order to characterize or modify the channel, one needs to develop highly accurate, electromagnetic-based propagation models for both indoor and outdoor applications. There are other means to improve the capacity of the channel; use of smart antennas, diversity techniques and multi element arrays. Smart antennas, fully adaptive or switched beam, can be utilized in mobile communications systems to mitigate the level of interference in an urban area where interference plays a major role in limiting the capacity of the channel. As a result, more communication channels can be added before the threshold is again crossed. However, multi element array technology, which is mainly considered in wireless LAN applications where there is limited mobility, works in Rayleigh fading environment. This communication structure utilizes multiple antennas at both the transmitter and receiver, and improves the channel capacity significantly.

The complexity and size of electronic systems being designed, for various applications from high performance computing to wireless and optical communications, is increasing everyday. As a result, the design iterations are becoming more and more expensive. First time correct designs are highly desired, to reduce both the design cost and time-to-market. This goal is achievable only with formal, rigorous and efficient algorithms and methodologies for design analysis and system performance prediction.

In the following, we propose solutions to these challenging technical problems.

Digital Video Streaming for Multimedia Communication
A. Murat Tekalp

Streaming video involves encoding and packetization of digital video. The main problem in streaming is that the throughput of the network may vary in time. Therefore, if the server does not take this throughput variation into account (especially for low-bandwidth channels, such as wireless video streaming), then many packets may never reach destination or may be delayed (which renders them useless). Streaming systems may be one-way (video-on-demand) or two-way (interactive). Furthermore, they may employ real-time or off-line video encoding. Assuming that the server can receive feedback on channel throughput at regular intervals, we propose several strategies in order to optimize the quality of the delivered video for a low-bandwidth streaming server. These strategies include transmission buffer control, switching between a fixed number of pre-encoded streams, layered coding, fine granular scalable coding, multiple description coding, error-resilient encoding at the server as well as post-processing at the receiver.

Video Object Segmentation and Tracking
A. Murat Tekalp

One of the most important tasks for content-based video processing is the segmentation and tracking of objects of interest (e.g., humans, cars, etc.) in the video. These objects may be used in object-based video compression or for higher-level video analysis tasks such as object recognition or event detection. Video object segmentation and tracking methods may be classified as those that follow a coarse outline (e.g. a bounding box) of the object vs. those which extract pixel-accurate contour of the object. We propose both a coarse tracker based on Kalman filtering of bounding box coordinates, as well as a pixel-accurate contour tracker for non-rigid objects using a piece-wise adaptive snake model of the contour.

Digital Speech and Audio Processing
Engin Erzin

Our research interests in digital speech and audio processing includes speech coding, speech recognition, text-to-speech synthesis. Speech and audio coding research mainly focuses on packet communication systems. Frame error recovery, error protection and classified variable rate coding could be listed as action items for speech and audio coding. There are also ongoing projects, which are related to speech recognition. We are working on a visual phoneme recognition system that drives a lip-synchronous animated talking head. Both statistical methods such as HMMs and VQ based classification techniques are being used for lip-sync problem. A limited vocabulary continuous speech recognition with a Turkish language model is also targeted. Audio-visual content classification problem is another related topic that is going to be addressed. Finally we have an active project to build LP-based concatenative text-to-speech synthesis system for Turkish.

Automatic Multimedia Indexing and Summarization: Joint Audio-Video Processing
A. Murat Tekalp and Engin Erzin

Automatic video analysis for indexing and summarization involves both low-level and semantic-level analysis. Low-level video analysis includes temporal video segmentation, object-based content analysis of each temporal segment, and extraction of color, shape, and motion descriptors for each object. Semantic level tasks include object recognition, and event detection. There is also valuable information in the audio track for semantic level video analysis. In particular, we propose combined audio-video processing techniques for event detection in sports video.

Authentication Watermarking for Digital Video
A. Murat Tekalp

Digital video has become increasingly susceptible to spatio-temporal manipulations as a result of recent advances in video editing tools. We propose a secure and flexible fragile digital video authentication watermark, which also enables the self-recovery of video content after malicious manipulations. In the proposed block-based method, the watermark payload of a block is composed of two parts: authentication and recovery packets. The authentication packet is a digital signature with a special structure and carries the spatio-temporal position of the block. The digital signature guarantees the authenticity and integrity of the block as well as the recovery packet, whereas the localization information prevents possible cut-and-paste attacks. On the other hand, recovery packet contains a highly compressed version of a spatio-temporally distant block. This information enables the recovery of the distant block, upon detection of tampering by its authentication packet. A spatio-temporal interleaving scheme and a simple multiple description coding mechanism increase the probability of self recovery by diffusing recovery information throughout the sequence. Finally, watermark payload is embedded by least significant bit modulation.

Secure Access: Biometric Person Identification
Engin Erzin, A. Murat Tekalp and Yücel Yemez

Biometric identification technologies include recognition of faces, fingerprints, voice, signature strokes, iris and retina scans, and gait. Biometric identification problems can be classified as recognition and authentication problems. The former refers to identification of a person from biometric data from a set of candidates, while the latter refers to verification of a person's biometric data. It is generally agreed that no single biometric technology will meet the needs of all potential recognition and authentication applications. Although the performance of several of these biometric technologies has been studied individually, there is very little work reported in the literature on the fusion of the results of various biometric identification technologies. Hence, we propose to focus on integration of all these individual biometric technologies in a single multi-stage and multi-modal biometric identification system.

3D Computer Graphics, Object Reconstruction and Geometric Modeling
Yücel Yemez

3D object models, computer generated or reconstructed from scanned real data, are becoming more commonplace as an essential part of the audio-visual data of the virtual world and the emerging multimedia technologies. These 3D models may represent objects for various applications in many domains such as e-commerce, entertainment, education, architecture, cultural preservation, CAD and medical applications, construction and automation. Once constructed, they can be stored in local databases, transmitted for instance through the Internet and visualized or manipulated when needed. The increasing popularity of 3D models, that can sometimes be very large in terms of data size, has activated various relatively recent research areas for developing efficient ways of reconstructing and modeling 3D object data. In this respect we focus on the following specific research areas:

- 3D digitization of archeological findings and museum art objects; such valuable objects constitute part of the cultural heritage and once digitized, they can be used in construction of virtual archeological sites and virtual museums.
- Progressive modeling, visualization and streaming of high resolution 3D models for applications such as navigation or browsing with limited bandwidth transmission.
- 3D object model recognition

Scalable Multicast Communication
Oznur Ozkasap

Multicast, a way of transmitting a message to the members of a specified group of processes, is an important communication paradigm for constructing distributed computing applications. The abstraction of a group is a logical name for a set of processes whose membership may change with time. Groups are mainly used in distributed systems for distributing information and work, replicating data, naming and monitoring. The development of high-speed networks and the expansion of the Internet have increased both geographical extent and participant population of applications such as videoconferencing, multimedia dissemination, electronic stock exchange, and distributed cooperative work. The key property of this type of applications is the need to distribute data among multiple participants together with application specific quality of service needs which fact makes multicast transport protocols an essential underlying communication structure. Several distributed applications exploiting multicast communication require reliable delivery of data to all participants. In addition, scalability, throughput stability, efficient loss recovery and buffer management are essential communication properties in large-scale settings that we focus on.

Wireless Packet Networks Supporting Multicast Services
Oguz Sunay and Oznur Ozkasap

Traditionally, wireless communications systems have been optimized for providing voice services in an efficient and reliable manner. With the explosive growth of the Internet

usage, the third generation wireless cellular systems strive to provide high-speed packet data services as well. In this context, the physical and MAC layer specifications of such systems need to take the existence of packet data services into account. It has been shown that wireless cellular communication systems optimized towards the voice services are not suitable for efficient high-speed packet data access. If multicast services are to be supported as part of packet data transmission, the physical and MAC layer specifications for efficient communications may need to be altered. Research on multicast routing and transport protocols for wireless systems has gained importance in recent years. In general one can divide wireless systems into two categories, namely, cellular systems and wireless ad-hoc systems. In cellular systems, users are supported by means of a hierarchical backbone network, whereas, in ad-hoc systems, the users themselves act as part of the network. In other words, in ad-hoc networks, support of one user may include involvement from other users as well as the backbone network.

Low Profile Antennas - Analysis and Design
Irsadi Aksun

Since the antennas are indispensable parts of any wireless communications systems, their accurate and efficient analysis would help designers to design antennas with better performances. We have developed several techniques, ranging from rigorous and very accurate to approximate but very efficient, to analyze low-profile printed antennas. As a result of combining these techniques with some suitable optimization algorithms, we were able to develop a CAD tool for designing antennas with predefined polarization and radiation patterns over frequency bands of interest. This tool, together with the expertise we have gained over the years, can be used to design the physical antennas for smart antenna applications as well as for multi-element array (MEA) applications, both of which may require dual-polarized, dual-band, and steer-able antennas.

Development of Propagation Models in Indoor and Outdoor Environments
Irsadi Aksun and Oguz Sunay

Due to the rapid development of wireless communications market, there has been an intense investigation on the prediction of radio propagation in indoor and outdoor environment. In outdoors, some empirical formulas, developed statistically, were mainly used to predict the field strength, while more accurate but less efficient approaches, like ray tracing, need be employed in more complicated indoor environments. We have developed a hybrid method, based on ray-tracing and wave-guiding in layered media, for the prediction of field strength in urban areas where buildings form uniform corridor like structures. Since it is almost impossible to account for every interaction of the radio signal with the complex indoor environment, we have developed an EM based approach, where we model the corridors and walls as layered media, and find the field strength as the solution of Maxwell’s equations in it.

Development of Accurate and Efficient EM-based Simulation Methods
Irsadi Aksun

For the design of RF circuits, which are the integral parts of any communications systems, one usually needs an efficient and accurate simulation tool, to reduce the

number of trial-and-error iterations. Although there are several CAD tools available commercially that target this problem, they don't provide efficiency and accuracy simultaneously; some are accurate but numerically very inefficient, others are efficient but not accurate enough. Therefore, we have developed a new approach to analyze printed circuits with great accuracy without sacrificing the efficiency. This approach is based on the solution of the mixed-potential integral equation, derived from Maxwell's equation for layered media, by the method of moments in conjunction with the closed-form Green's functions.

Adaptive and Blind Equalization Algorithms for Multi-User and Multi-Branch Transceiver Systems
Alper Erdogan and Oguz Sunay

Equalization is the general name for the process of inverting the adverse effects of the communication medium on the information bearing signals. The goal of equalization is dependent on the transmit modulation as well as the multiple access scheme. For single carrier systems, the goal is to convert the overall effect of the channel into that of a simple delay channel, by removing the inter symbol interference caused by the distortion of the communication channel. In DMT based multi-carrier signaling schemes, such as OFDM and VDSL, the goal is to reduce the channel spread into a length less than the prefix length of the DMT symbols. In both cases, the crosswalk from the co-channel users creates an additional challenge. The existence of multiple branches, such as multiple antennas in wireless communications or over sampled receivers, is a source of diversity that can be exploited for both equalization and cross-talk mitigation. The development of low complexity and high performance adaptive and blind algorithms for multi-user communications systems and multi-branch transceivers is our research focus. We also analyze the performance of the proposed algorithms in relation to the achievable levels and the levels of the existing algorithms.

Design Analysis and Methodology for Analog RF Front-Ends
Alper Demir

Even though there is a trend to make electronic systems more and more digital or discrete, every system still has an analog part, i.e., front-end, that cannot be converted into the realm of binary numbers. First of all, every system has to interface with the real world, which is inherently analog or mixed-signal and is composed of electromagnetic waves in the atmosphere or a waveguide, noise, nonlinearities, etc. The analog and RF front-end is arguably the bottleneck in the design of electronic systems. Nonlinear electronics/integrated circuits for RF/wireless/high-speed communications (e.g., oscillators, mixers, low-noise amplifiers, filters, phase/frequency-locked loops) are important examples of the analog parts in the communication systems being designed today.

The design and design analysis problem is already extremely difficult for the analog/RF front-ends of communications systems. It is getting even more challenging due to the

trend to integrate more and more analog and digital functionality on the same integrated circuit, and create a system-on-a-chip.

The principal goal of our research will be to develop rigorous and efficient algorithms for the design analysis and formal design methodologies for the analog part (integrated with digital processing blocks on the same integrated circuit) that forms the bottleneck in communication system design. We believe that this goal is achievable only through the undertaking of real practical designs of analog RF front-ends.

The goals of our research work are three-pronged:

1. Develop a fundamental and physical understanding of nonideal or unwanted phenomena that effect system behavior: Noise, random, nonlinear and time-varying phenomena, specialized dynamics, interference between system components due to various forms of coupling, digital switching interference from the digital part of a mixed-signal chip to the sensitive analog circuits, interaction of useful signals, noise, interference and nonlinearities.

2. Develop mathematical models, formulate rigorous analysis techniques, and develop efficient numerical methods for the analysis of the above phenomena and the component/system design problem. Emphasize rigorous formulation and analytical understanding, and identify the most appropriate mathematical concepts and tools from stochastic processes, linear/nonlinear/stochastic dynamical systems, and numerical analysis for the proper formulation of the design analysis problem and for efficient numerical methods. For analysis of noise and statistical phenomena, replace existing brute-force and inefficient Monte-Carlo based simulation approaches with semi-analytical, efficient and accurate numerical techniques. Exploit hierarchy and use mathematical abstraction to tackle the analysis of complex and large systems, by using existing techniques for reduced-order/reduced-complexity modeling or developing new techniques as appropriate.

3. Develop new design methodologies or processes, which will make use of the newly developed models and analysis techniques, or introduce them into existing methodologies. Tackle real designs, both personally and through collaboration with others, both for identification of real design problems, and for the testing and calibration of the models and analysis algorithms developed to solve them. Promote the use of new models and analysis techniques and demonstrate their effectiveness in solving real design problems.

Faculty Involved in this Proposal

Faculty		PhD	Research Area
A. Murat	Tekalp	Rensselaer Polytechnic Institute, 1984	Digital image and video processing
Irsadi	Aksun	University of Illinois,	Antennas and propagation
M. Reha	Civanlar	North Carolina State University, 1984	Multimedia networking
Oğuz	Sunay	Queen`s University, 1997	Wireless communication systems
Alper	Erdogan	Stanford University	Digital communications, signal processing
Engin	Erzin	Bilkent University, 1995	Speech coding, recognition, synthesis
Öznur	Özkasap	Ege University, 2000	Distributed computing systems and networks
Yücel	Yemez	Bogazici University, 1997	Computer graphics, vision, signal processing
Alper	Demir	UC Berkeley, 1997	Electronics