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Signal Processing for Networking and Communications

The general field of signal processing for networking and communications (SPCOM) is dedicated to exploring and illuminating connections between signal processing, communications, and information theory. In its early days, SPCOM was focused on physical layer technologies. Later the emphasis shifted to wireless communication and more recently the embrace of networking. SPCOM is now exploding with advances in wireless networking as well as new research directions. This article documents our personal views on trends in SPCOM expressed during the expert summary, which was organized by the SPCOM Technical Committee (SPCOM–TC) at ICASSP 2011. It is by no means exhaustive nor does it include a detailed bibliography, rather it includes select trends that, in our opinion, will shape the future of SPCOM.

COGNITIVE NETWORKS

Cognitive communication systems make spectrum reuse more efficient by allowing secondary users to share spectrum with existing primary users, provided that the primary users retain some level of protection. Spectrum sensing and resource allocation are ongoing research topics in cognitive radio. Challenges in spectrum sensing include collaborative sensing among secondary users, exploiting limited feedback from primary receivers for better protection, and cross-layer design of sensing and communication. Challenges in resource allocation include dynamic rate maximization subject to retaining a level of protection for the primary users, game-theoretic multiradio optimization, multihop cognitive networks, and joint resource allocation and sensing.

COOPERATIVE INTERFERENCE MANAGEMENT

Most wireless communication systems are interference limited. Recent work has recognized that the effects of interference can be reduced through cooperative interference management, where some cooperation is employed between transmitters. Interference alignment, where transmit precoders are specially designed so that interference occupies a reduced dimension subspace, is one approach for interference management. Another example is base station coordination, where the cellular backhaul is leveraged to coordinate transmissions. Research is needed on interference management to understand performance limits, develop practical precoder and decoder designs, deal with multichannel limited feedback of channel state information, synchronize transmissions, and understand the impacts of overheads.

[SPCOM IS DEDICATED TO EXPLORING AND ILLUMINATING CONNECTIONS BETWEEN SIGNAL PROCESSING, COMMUNICATIONS, AND INFORMATION THEORY.]

HETEROGENEOUS NETWORKS

Heterogenous networks break through capacity bottlenecks in the conventional macrocell cellular architecture, using features such as small cellular access points (picocells and femtocells), fixed relays, and distributed antennas. The successful deployment of heterogeneous networks will require new advances in signal processing. For example, scalable algorithms in the form of beamforming or precoding, equalization, scheduling, and feedback are needed to align, avoid, or otherwise deal with the interference. Decentralized algorithms are needed to support autonomous operation of the nodes, allowing for delays and overhead in the backhaul connections. Other relevant topics include channel estimation and limited feedback techniques considering the interference-limited characteristics of heterogeneous networks, not to mention coexistence, access control, synchronization, and self-organized network design.

UNDERWATER AND OPTICAL COMMUNICATIONS

Wireless communication in SPCOM is becoming less traditional. Acoustic underwater communication is shifting from peer-to-peer noncoherent communications towards underwater networks and coherent communications. Interest is growing in underwater sensor networks for applications like tsunami detection and water quality monitoring. Research challenges include large delay and Doppler spreads, slow and anisotropic propagation, and distance-dependent bandwidths. Visible light communication (VLC) is another promising area that has yet to receive significant attention in SPCOM. VLC is enabled by light emitting diode (LED)-based communication, which due to massive deployment, provide a free communication resource that can be explored for a plethora of new applications, i.e., smart lighting, car-to-car communications, and wireless system control. Signal processing for VLC is still in its early stages, providing a new application for MIMO techniques.

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GOING BEYOND TRADITIONAL NETWORKS: SMART GRID, INTELLIGENT INFRASTRUCTURE, AND SOCIAL NETWORKS

SPCOM is evolving to incorporate new networking concepts. The smart grid adds communication networking capability to an infrastructure network like the power grid or water grid. For example, the power grid can deliver power much more efficiently when real-time information about the grid state is available through networked meters and power infrastructure. Challenges in the smart power grid include developing machine-to-machine network protocols for reporting measurements, better techniques for large-scale network state estimation, and robustness to cyber attacks. The smart grid is just one example of a more general trend of networks-of-networks where different networking concepts are used to make infrastructure more intelligent. More examples include intelligent transportation systems, which use vehicle-to-vehicle networks to improve transportation network safety and efficiency. Mathematical tools from SPCOM are also being used to understand noncommunication networks like social networks.

COMPRESSIVE SENSING IN SPCOM

Compressive sensing (CS) refers to efficient compression and reconstruction of analog signals that are sparse in some domain, e.g., space, time, or frequency. CS is a component of many different technical committees. In SPCOM, CS has been applied to the detection of impulse radio ultrawideband (exploits time-domain sparsity), radar (exploits sparsity in angle, Doppler, and/or range domain), and spectrum sensing (exploits sparsity in the spectrum). There are many applications of CS remaining in SPCOM, including localization and tracking through radar, or better navigation through global network satellite systems. Challenges remain, especially in evaluating the viability of CS versus non-CS techniques.

LOCALIZATION

Determining location is receiving renewed interest in SPCOM coupled with applications such as sensor networks for telemetry and satellite navigation. For low-energy sensor applications, range-based localization is receiving attention where distance measurements between sensors and beacons and/or among the sensors themselves are exploited to compute the location of the sensors. Assisted satellite navigation is also likely to become more important, where signals of opportunity are exploited. New mathematical tools that are being exploited in localization include CS and multidimensional scaling.

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Slides

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Signal Processing Theory and Methods

The scope of the IEEE Signal Processing Theory and Methods (SPTM) Technical Committee has a broad span, ranging from digital filtering and adaptive signal processing to statistical signal analysis, estimation, and detection. There have also been significant advances in the estimation of sparse systems. These areas continue to play a key role in classical and timely applications.

Under the unifying theme "how simple local behavior generates rational global behavior," an SPTM expert session was organized by the authors during ICASSP 2011 in Prague. This article summarizes the session and raises challenging questions for future research. It is by no means representative of all emerging topics in the areas of SPTM, but it includes trends and challenges that, in our opinion, will become important activities in SPTM in the coming years. The bibliography is not exhaustive due to space limitations; it only gives some representative references the readers may want to consult.

IN-NETWORK PROCESSING, LEARNING, AND ADAPTATION

Cognitive or adaptive networks are composed of spatially distributed agents that share information over a graph. The topology of the graph may evolve dynamically over time due to movement of the agents or because agents wish to collaborate with other agents and form coalitions (see [1] and the references therein). Each agent possesses adaptation and learning abilities

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