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ETPL WC - 001	Two-Stage Multiple Access for Many Devices of Unique Identifications over Frequency-Selective Fading Channels

In this paper, we consider sparse index multiple access for uplink random access in a wireless system of a number of devices when a fraction of them are active. This multiple access scheme is suitable for the case that an access point (AP) needs not only to receive data symbols, but also to identify active devices when there are a number of devices with unique identification sequences (the number of devices can be easily more than a million) with low signalling/control overhead. We propose a two-stage transmission scheme for random access and derive computationally efficient methods to estimate the channel state information (CSI) of active devices over frequency-selective fading channels in the first stage and to perform joint active device identification and data detection in the second stage using a well-known sparse signal estimation method in compressive sensing. Simulation results demonstrate that the proposed approach can successfully estimate the CSI of active devices under reasonable conditions and identify the unique identification sequences or vectors of active devices with a high probability. For example, when 6 out of 64 devices become active, the AP can identify all six devices (using estimated CSI) with a probability higher than $1 - 10^{-2}$ over frequency-selective fading channels.

ETPL WC - 002	Soft Combination for Cooperative Spectrum Sensing in Fading Channel

In this paper, we study the distributed energy-based detectors for spectrum sensing in cognitive radio networks. We assume that the sensing channel includes both small-scale and large-scale fading. The small-scale fading is modeled as Nakagami-m and independent for different cooperating cognitive users, while the large-scale fading is assumed to be known (or can be estimated) by the cognitive users, due to their slowly changing nature. Furthermore, we assume that the channel gains are constant in one observation interval and vary independently in different intervals. Based on the Bayesian rule, we derive the optimal energy combining rule, i.e., the average likelihood ratio (ALR) detector. We also suggest two solutions: 1) mixture of gamma (MoG)-based ALR detector and 2) generalized Gauss-Laguerre formula (GLF)-based ALR detector, to overcome the problem of the intractable integrals in the optimal rule, and we propose two novel suboptimal but practical combining rules: 1) GLF-based linear combining detector, which can be implemented by linear functions and a comparator with negligible performance degradation and 2) GLF-based weighted-energy detector applicable for the low SNR regime. The simulation results reveal that with MoG and GLF detectors, the ALR detector can be implemented almost precisely with lower complexity. Moreover, all the proposed detectors outperform the conventional ones, especially when large-scale channel gains differ for different cognitive users.

ETPL WC - 003	Performance Analysis of Beam forming in MU-MIMO Systems for Rayleigh Fading Channels

This paper characterizes the performance metrics of MU-MIMO systems under Rayleigh fading channels in the presence of both cochannel interference and additive noise with unknown channel state information and known correlation matrices. In the first task, we derive analytical expressions for the cumulative distribution function of the instantaneous signal-to-interference-plus-noise ratio (SINR) for any deterministic beamvectors. As a second task, exact closed-form expressions are derived for the instantaneous capacity, the upper bound on ergodic capacity, and the Gram-Schmidt orthogonalization-based ergodic capacity for similar intra-cell correlation coefficients. Finally, we present the utility of several structured-diagonalization techniques, which can achieve the tractability for the approximate solution of ergodic capacity for both similar as well as different intra-cell correlation matrices. The novelty of this paper is to formulate the received SINR in terms of indefinite quadratic forms, which allows us to use complex residue theory to characterize the system behaviour. The analytical expressions obtained closely match simulation results.

ETPL WC - 004	Mixed mm Wave RF/FSO Relaying Systems over Generalized Fading Channels with Pointing Errors

This paper studies the performance of mixed millimeter-wave radio-frequency (mmWave RF), free-space optics (FSO) systems in a highly scalable and cost-effective solution for fifth-generation (5G) mobile backhaul networks. The mmWave RF and FSO fading channels are, respectively, modeled by the Rician and the generalized Malaga (M) distributions. The effect of pointing errors due to the misalignment between the transmitter and the receiver in the FSO link is also included. Novel accurate closed-form expressions for the cumulative distribution function, the probability density function, and the moment generating function (MGF) in terms of Meijer's G functions are derived. Capitalizing on these new results, we analytically derive precise closed-form expressions for various performance metrics of the proposed system, including the outage probability, the average bit error rate (ABER), and the average capacity. Additionally, new asymptotic results are provided for the outage probability, the MGF, and the ABER in terms of simple elementary functions by applying the asymptotic expansion of the Meijer's G function at high signal-to-noise ratios (SNRs). Numerical results further validate the mathematical analysis by Monte-Carlo simulations.

ETPL WC - 005	Performance Analysis of Multihop Parallel Free-Space Optical Systems over Exponentiated Weibull Fading Channels

The performances of multihop parallel free-space optical (FSO) cooperative communication systems with decode-and-forward protocol under exponentiated Weibull (EW) fading channels have been investigated systematically. With the max-min criterion as the best path selection scheme, the probability density function and the cumulative distribution function of the max-min EW random variable are derived. The analytical expressions for the average bit error rate (ABER) and outage probability with identically and independently distributed (i.i.d.) links are then obtained, respectively. Based on it, the ABER for a non-identically and independently distributed (non-i.i.d.) FSO system is also deduced with the help of the Gauss-Laguerre quadrature rule. The ABER performance of the considered system are further analyzed, in detail, under different turbulence conditions, receiver aperture sizes, and structure parameters (R and C). The comparison between i.i.d. and non-i.i.d. FSO systems over EW fading channels shows that the performances of both systems could be improved with large aperture diameters adopted for the structure parameters R and C selected. Monte Carlo simulation is also provided to confirm the correctness of the analytical ABER expressions. This work presents a generalized system model, and it can be used to analyze and design FSO communication systems.

ETPL WC - 006	Full-Duplex Regenerative Relaying and Energy-Efficiency Optimization over Generalized Asymmetric Fading Channels

This paper is devoted to the end-to-end performance analysis, optimal power allocation (OPA), and energy-efficiency (EE) optimization of decode-and-forward (DF)-based full-duplex relaying (FDR) and half-duplex relaying (HDR) systems. Unlike existing analyses and works that assume simplified transmission over symmetric fading channels, we consider the more realistic case of asymmetric multipath fading and shadowing conditions. To this end, exact and asymptotic analytic expressions are first derived for the end-to-end outage probabilities (OPs) of the considered DF-FDR set ups. Based on these expressions, we then formulate the OPA and EE optimization problems under given end-to-end target OP and maximum total transmit power constraints. It is shown that OP in FDR systems is highly dependent upon the different fading parameters and that OPA provides substantial performance gains, particularly, when the relay self-interference (SI) level is strong. Finally, the FDR is shown to be more energy-efficient than its HDR counterpart, as energy savings beyond 50% are feasible even for moderate values of the SI levels, especially at larger link distances, under given total transmit power constraints and OP requirements.

ETPL WC - 007	On the Efficient Simulation of the Distribution of the Sum of Gamma–Gamma Variates with Application to the Outage Probability Evaluation over Fading Channels

The Gamma-Gamma distribution has recently emerged in a number of applications ranging from modeling scattering and reverberation in sonar and radar systems to modeling atmospheric turbulence in wireless optical channels. In this respect, assessing the outage probability achieved by some diversity techniques over this kind of channels is of major practical importance. In many circumstances, this is related to the difficult question of analyzing the statistics of a sum of Gamma-Gamma random variables. Answering this question is not a simple matter. This is essentially because outage probabilities encountered in practice are often very small, and hence, the use of classical Monte Carlo methods is not a reasonable choice. This lies behind the main motivation of this paper. In particular, this paper proposes a new approach to estimate the left tail of the sum of Gamma-Gamma variates. More specifically, we propose robust importance sampling schemes that efficiently evaluates the outage probability of diversity receivers over Gamma-Gamma fading channels. The proposed estimators satisfy the well-known bounded relative error criterion for both maximum ratio combining and equal gain combining cases. We show the accuracy and the efficiency of our approach compared with naive Monte Carlo via some selected numerical simulations.

ETPL WC - 008	Robust Stability Analysis and Synthesis for Uncertain Discrete-Time Networked Control Systems over Fading Channels

This technical note investigates uncertain discrete-time networked control systems over fading channels. It is assumed that the plant is affected by polytopic uncertainty and is connected to the controller in closed-loop via fading channels which are modeled by multiplicative noise processes. Three contributions are proposed as follows. First, it is shown that robust stability in the mean square sense of the uncertain closed-loop networked control system is equivalent to the existence of a Lyapunov function in a certain class. Second, it is shown that the existence of a Lyapunov function in such a class is equivalent to the feasibility of a set of linear matrix inequalities (LMIs). Third, it is shown that the proposed condition can be exploited for the synthesis of robust controllers ensuring robust stability in the mean square sense of the uncertain closed-loop networked control system.

ETPL WC - 009	Dual-Polarized Spatial Modulation over Correlated Fading Channels

We address multiple-input multiple-output (MIMO) communication employing spatial modulation (SM) with dual-polarized (DP) antennas. The proposed architecture adds the polarization dimension to the conventional SM mappings and offers performances, which are comparable to or under certain conditions even better than those of the uni-polarized systems while occupying half as much space. We consider the generalized spatially correlated Rayleigh and Rician fading channel models and present an average bit-error probability upper bounding framework for the proposed DP SM-MIMO system. The theoretical error analysis is also extended to the case where the channel coefficients are estimated with Gaussian estimation errors. This upper bounding method is also used to determine the conditions in which the dual-polarized SM is better than equivalent systems with uni-polarized antennas. Theoretical derivations are also validated by extensive simulations, both corroborating that SM combined with dual-polarization forms an attractive alternative not only for its improved multiplexing gains and space efficiency but also for performance gains over correlated channels.

ETPL WC - 010	Joint Antenna-and-Relay Selection in MIMO Decode-and-Forward Relaying Networks over Nakagami-m Fading Channels

Antenna selection and relay selection are two potent methods to enrich the system capacity by selecting the perfect one to function. In this letter, a downlink multiple-input multiple-output decode-and-forward relaying network is analyzed by considering Nakagami-m fading as a model for the channel gains. The system performance is analyzed by using a joint scheme (JS), which joints the relay selection and the antenna selection at the base station and the selected relay. A closed-form expression corresponding to the outage probability is derived, and the approximate expression of the outage probability in the high-signal-to-noise-ratio regime is obtained. Finally, simulations show the superiority of the JS.

ETPL WC - 011	Capacity of Nakagami- m Fading Channel with BPSK/QPSK Modulations

In this letter, we develop a recurrence formula for the capacity of Nakagami-m fading channel with BPSK/QPSK modulations when channel state information is available at the receiver. For each fading parameter m, a simply constructed series representation with a fast-convergence rate can be obtained through the recurrence formula. The series expansion provides a numerically efficient way to calculate the capacity for both Rayleigh and Nakagami-m fading channels. The simulation results show that the recurrence formula is a good alternative for estimating the capacity of Nakagami fading channel.

ETPL WC – 012	On Adaptive Power Control for Energy Harvesting Communication over Markov Fading Channels

We study a continuous-time power policy to maximize the ergodic channel throughput of an energy harvesting transmitter over a Markov fading channel. In particular, we consider transmission power policies that are adapted to the fading process of the channel as well as the storage process of the battery. We obtain a set of equations that determine the probability density of the energy in the battery at each channel state. Specifically, for an ergodic battery storage process, these equations describe the relation between the probability density of stored energy and the transmission power at each channel state. From these equations, we derive an upper bound on the average transmission power and an upper bound on the average transmission rate. To compute a lower bound on the average transmission rate, we apply a calculus of variations technique to a non-linear throughput maximization problem. As a result, we obtain a system of coupled ordinary differential equations for locally optimal power policies. We then focus on the Gilbert-Elliot channel as a special case and derive some structural results for specific classes of fast and slow fading channels. Furthermore, we numerically find a locally optimal transmission power policy for the two channel state scenario.

ETPL WC - 013	Performance Analysis of Cooperative Spectrum Sharing With Multiuser Two-Way Relaying Over Fading Channels

In this paper, we analyze the performance of an overlay multiuser two-way relay network with N th-user selection by employing a three-phase cooperative spectrum sharing (3PCSS) scheme. Hereby, a one-end primary user (PU) communicates with the arbitrary (which may be the N th best) selected other-end PUs with the cooperation of a secondary user (SU) in three transmission phases. By splitting up its available power, the SU assists in bidirectional primary transmissions and accesses the spectrum for its own transmission, based on satisfying the primary system outage constraint. Considering the involved N th-order statistics with correlation, we derive the outage probability expressions for both primary and secondary systems over general fading channels. Based on these expressions, we compute the total system throughput of the 3PCSS scheme and compare it with other competitive schemes. We illustrate that the 3PCSS scheme can effectively realize spectrum sharing by harnessing additional cooperative diversity and achieving spectral efficiency at par with the primary two-phase direct transmission system. Numerical and simulation results substantiate our theoretical findings.

ETPL WC - 014	Performance Analysis of Non orthogonal Multiple Access for Relaying Networks over Nakagami-m Fading Channels

Non-orthogonal multiple access (NOMA) has been conceived as a breakthrough technology for the fifth generation (5G) wireless networks. With imperfect channel state information (ICSI) taken into account, we study an NOMA-based downlink amplify-and-forward (AF) relaying network under Nakagami-m fading in this paper. First, we investigate the system outage behaviour, and close-form expressions for the exact and tight lower bounds of the outage probability are attained, respectively. By further evaluating the outage probability at the high SNR region, it is observed that an error floor exists in the outage probability due to the presence of ICSI. Finally, numerical results are presented to demonstrate the validity of our analysis and show the advantages of NOMA over conventional orthogonal multiple access. Moreover, simulation results verify that the optimal relay location for NOMA should be close to the source node.

ETPL WC - 015	Resource Allocation for D2D Communications Underlay in Rayleigh Fading Channels

Device-to-device (D2D) communication has attracted substantial research attention recently, due to its potential to improve coverage, spectrum efficiency, and energy efficiency within the existing cellular infrastructure. One major challenge for spectrum resource sharing in D2D underlay lies in the mutual interference between cellular user equipment's (CUEs) and D2D user equipment's (DUEs). Considering this mutual interference constraint, this work investigates the problem of optimal matching of D2D links and CUEs to form spectrum-sharing partners to maximize ergodic sum rates under transmit power and outage constraints. Unlike previous works, full channel-state information (CSI) is not required. To solve the resulting high-complexity problem, candidate DUE sets are first narrowed down according to required outage probability constraints, which are used to construct a simplified bipartite graph. The weight of the bipartite graph is characterized as the maximization of ergodic sum rate of the associated D2D and cellular links under outage constraints for which a low-complexity algorithm is proposed to solve the nonconvex problem. After constructing the bipartite graph, the Hungarian algorithm is used to determine the optimal pairing between D2D links and CUEs. Numerical results demonstrate that the proposed algorithm can improve the outage-constrained spectrum efficiency of D2D networks with practical complexity.

ETPL WC - 016	Optimal Power Allocation for Average Detection Probability Criterion over Flat Fading Channels

In this paper, the problem of optimal power allocation over flat fading additive white Gaussian noise channels is considered for maximizing the average detection probability of a signal emitted from a power constrained transmitter in the Neyman-Pearson framework. It is assumed that the transmitter can perform power adaptation under peak and average power constraints based on the channel state information fed back by the receiver. Using results from measure theory and convex analysis, it is shown that this optimization problem, which is in general nonconvex, has an equivalent Lagrangian dual that admits no duality gap and can be solved using dual decomposition. Efficient numerical algorithms are proposed to determine the optimal power allocation scheme under peak and average power constraints. Furthermore, the continuity and monotonicity properties of the corresponding optimal power allocation scheme are characterized with respect to the signal-to-noise ratio for any given value of the false alarm probability. Simulation examples are presented to corroborate the theoretical results and illustrate the performance improvements due to the proposed optimal power allocation strategy.

ETPL WC - 017	Energy-Efficient Relay Selection of Cooperative HARQ Based on the Number of Transmissions over Rayleigh Fading Channels

Cooperative hybrid automatic retransmission request (C-HARQ) is a simple and effective method for wireless communication. Since its performance largely depends on the selection of a relevant relay, the design of an appropriate relay selection scheme is very important. Although various works have been performed on this topic, most of them did not take into account both the “not memory less” and multiple retransmission characteristics of C-HARQ, resulting in the loss of achievable performance. In this paper, we propose a novel cooperative relay selection scheme in a distributed manner called transmission number relaying (TNR) to simultaneously reduce the outage probability and increase the energy efficiency by utilizing the features of C-HARQ. The TNR scheme determines a single relay based on the estimated number of transmissions, which is calculated from the channel condition. Using these numbers instead of just the channel condition improves the outage probability and reduces the total consumed energy. The exact probability of the number of transmissions at each relay and the outage probability are analyzed, and the numerical results show that the proposed scheme significantly improves the outage probability and reduces the total consumed energy. In addition, when the number of available relays is small, the proposed scheme achieves high energy efficiency.

ETPL WC - 018	Soft-Decision-Aided, Smoothness-Constrained Channel Estimation over Time-Varying Fading Channels With No Channel Model Information

We consider frequency-flat time-varying fading channels with no channel model information (CMI). By introducing the smoothness function to measure the extent of channel fluctuation, we derive a robust soft-decision-aided (SDA) channel estimator based on Pareto optimality of the double-objective optimization of the likelihood function of the received signal sequence and the smoothness constraint of the channel estimates. Compared with the conventional maximum-likelihood-based channel estimators derived under the block-fading assumption, the newly derived SDA-Pareto estimator gives more freedom to the channel estimation process, allowing channel estimates to have controlled variations to track the time-varying channel more closely. Compared with estimators derived based on the maximum a posteriori probability or the minimum mean-square error criterion which require explicit acquisition of the CMI, the SDA-Pareto estimator significantly simplifies the channel measurement process by requiring only a suitable regularization parameter to balance the trade-off between the likelihood function and the smoothness condition. An adaptive algorithm is proposed to adjust the regularization parameter adaptively, enabling an efficient and effective implementation of the SDA-Pareto estimator in practical applications. Simulation studies are provided to demonstrate the advantage of the SDA-Pareto estimator over the conventional estimators in both channel estimation accuracy and error-rate performance.

ETPL WC - 019	Packet Error Rate Analysis of Uncoded Schemes in Block-Fading Channels Using Extreme Value Theory

We present a generic approximation of the packet error rate (PER) function of uncoded schemes in the additive white Gaussian noise channel using extreme value theory (EVT). The PER function can assume both the exponential and the Gaussian Q-function bit error rate forms. The EVT approach leads us to a best closed-form approximation, in terms of accuracy and computational efficiency, of the average PER in block-fading channels. The numerical analysis shows that the approximation holds tight for any value of signal-to-noise ratio (SNR) and packet length whereas the earlier studies approximate the average PER only at asymptotic SNRs and packet lengths.

ETPL WC - 020	Energy-Efficient Power Control Algorithms in Massive MIMO Cognitive Radio Networks

To achieve the maximum network energy efficiency (EE) and guarantee the fairness of EE among cognitive users (CUs), respectively, in the massive multiple-input multiple-output cognitive radio network, we investigate two power optimization problems: network EE optimization problem (NEP) and fair EE optimization problem (FEP) under a practical power consumption model. Because of the fractional nature of EE and the interference, both NEP and FEP are non-convex and NP-hard. To tackle these issues, we propose two energy-efficient power control algorithms, in which we decompose NEP/FEP into two steps, and solve them with an alternating iterative optimization scheme. Specifically, in the first step, for an initial transmit power, the maximum network EE/fair EE is achieved by the bisection method based on fractional programming; then, with the achieved EE, in the second step, the adapted optimal transmit power can be obtained by an efficient iterative algorithm based on sequential convex programming. These two steps are performed alternately until the stop conditions are reached. Numerical results confirm the fast convergence of these proposed algorithms and demonstrate their effectiveness with high network EE and well fairness of EE among CUs. Furthermore, it is illustrated that, under a practical power consumption model, more cognitive base station antennas would cause some loss of network EE but bring some improvements on the network spectral efficiency (SE), whereas higher circuit power consumption would reduce the network EE but only slightly affect the network SE.

ETPL WC - 021	Semi-Cognitive Radio Networks: A Novel Dynamic Spectrum Sharing Mechanism

In conventional cognitive radio networks, channels that are in use by opportunistic secondary users (SUs) can be recaptured by the network's licensed primary users (PUs) at will, thus interrupting the connectivity of the former. To compensate for this, we propose here a semi-cogntive radio network (SCRN) paradigm where PUs are constrained to first use all free channels in the network before being allowed to capture channels that are currently in use by SUs. By imposing a monetary (or other) penalty to the network's secondary spectrum owners when opportunistic channel use becomes excessive, this additional constraint only induces a slight drop in the PUs' performance while offering significant benefits to the network's SUs. In this paper, we provide a game-theoretic analysis of such systems and we derive both centralized and decentralized adaptive algorithms that allow the system control process to converge to a stable equilibrium state. Our numerical results show that, with the same channel efficiency, SCRNs provide increased profits to the primary network and significantly reduced interruption rates to the secondary network.

ETPL WC - 022	Secure Cooperative Half-Duplex Cognitive Radio Networks with K -th Best Relay Selection

In this paper, we study the secrecy performance of a half-duplex cognitive relay network in the presence of multiple eavesdroppers and multiple primary users. In particular, generic K th best relay selection schemes for opportunistic relay selection (ORS) and partial relay selection (PRS) are proposed. Exact closed-form and asymptotic expressions for secrecy outage probability (SOP) of the considered schemes are derived. The outcome shows that ORS is able to achieve full secrecy diversity order while PRS obtains unit diversity order. Besides, the order of the selected relay is proved to affect the secrecy diversity order in the ORS scheme but not the PRS scheme, while the number of primary users does not have influence on the diversity order. Additionally, the significance of the change in the number of relays on the SOP enhances at higher orders of selected relay. Nevertheless, increasing the number of eavesdroppers reduces the secrecy diversity gain of the considered system in both schemes.

ETPL WC - 023	QoS Driven Channel Selection Algorithm for Cognitive Radio Network: Multi-User Multi-Armed Bandit Approach

In this paper, we deal with the problem of opportunistic spectrum access in infrastructure-less cognitive networks. Each secondary user (SU) Tx is allowed to select one frequency channel at each transmission trial. We assume that there is no information exchange between SUs, and they have no knowledge of channel quality, availability, and other SUs actions, hence, each SU selfishly tries to select the best band to transmit. This particular problem is designed as a multi-user restless Markov multi-armed bandit problem, in which multiple SUs collect a priori unknown reward by selecting a channel. The main contribution of the paper is to propose an online learning policy for distributed SUs, that takes into account not only the availability criterion of a band but also a quality metric linked to the interference power from the neighboring cells experienced on the sensed band. We also prove that the policy, named distributed restless QoS-UCB, achieves at most logarithmic order regret, for a single-user in a first time and then for multi-user in a second time. Moreover, studies on the achievable throughput, average bit error rate obtained with the proposed policy are conducted and compared to well-known reinforcement learning algorithms.

ETPL WC - 024	Proactive Spectrum Sharing for SWIPT in MIMO Cognitive Radio Systems Using Antenna Switching Technique

In this paper, we consider simultaneous wireless information and power transfer for spectrum sharing (SS) in a multiple-input multiple-output cognitive radio (CR) network. The secondary transmitter (ST) selects only one antenna, which maximizes the received signal-to-noise ratio at the secondary receiver (SR) and minimizes the interference induced at the primary receiver (PR). Moreover, PR is an energy harvesting node using the antenna switching, which assigns a subset of its antennas to harvest the energy and assigns the rest to decode its information data. The objective of this paper is to show that the SS is advantageous for both SR and PR sides and leads to a win–win situation. To illustrate the incentive of the SS in CR network, we evaluate the energy and data performance metrics in terms of the average harvested energy, the power outage, and the mutual outage probability, which declares a data outage event if the PR or SR is in an outage. We present some special cases and asymptotic results of the derived analytic results. Through the simulation results, we show the impact of various simulation parameters and the benefits due to the presence of ST.

ETPL WC - 025	Transmit Pre coding for Interference Exploitation in the Underlay Cognitive Radio Z-channel

This paper introduces novel transmit precoding approaches for the cognitive radio (CR) Z-channel. The proposed transmission schemes exploit noncausal information about the interference at the secondary base station to redesign the CR precoding optimization problem. This is done with the objective to improve the quality of service (QoS) of secondary users by taking advantage of constructive interference in the secondary link. The precoders are designed to minimize the worst secondary user's symbol error probability (SEP) under constraints on the instantaneous total transmit power, and the power of the instantaneous interference in the primary link. The problem is formulated as a bivariate probabilistic constrained programming (BPCP) problem. We show that the BPCP problem can be transformed for practical SEPs into a convex optimization problem that can be solved, for example, by the barrier method. A computationally efficient tight approximate approach is also developed to compute the near-optimal solutions. Simulation results and analysis show that the average computational complexity per downlink frame of the proposed approximate problem is comparable to that of the conventional CR downlink beam forming problem. In addition, both the proposed methods offer significant performance improvements as compared to the conventional CR downlink beam forming, while guaranteeing the QoS of primary users on an instantaneous basis, in contrast to the average QoS guarantees of conventional beam formers.

ETPL WC - 026	An Efficient Pre coder Design for Multiuser MIMO Cognitive Radio Networks with Interference Constraints

We consider a linear precoder design for an underlay cognitive radio multiple-input multiple-output (MIMO) broadcast channel, where the secondary system consisting of a secondary base station (BS) and a group of secondary users is allowed to share the same spectrum with the primary system. All the transceivers are equipped with multiple antennas, each of which has its own maximum power constraint. Assuming zero-forcing (ZF) method to eliminate the multiuser interference, we study the sum rate maximization problem for the secondary system subject to both per-antenna power constraints at the secondary BS and the interference power constraints at the primary users. The problem of interest differs from the ones studied previously that often assumed a sum power constraint and/or single antenna employed at either both the primary and secondary receivers or the primary receivers. To develop an efficient numerical algorithm, we first invoke the rank relaxation method to transform the considered problem into a convex–concave problem based on a downlink-uplink result. We then propose a barrier interior-point method to solve the resulting saddle point problem. In particular, in each iteration of the proposed method we find the Newton step by solving a system of discrete-time Sylvester equations, which help reduce the complexity significantly, compared to the conventional method. Simulation results are provided to demonstrate fast convergence and effectiveness of the proposed algorithm.

ETPL WC - 027	A Novel Spectrum Sensing for Cognitive Radio Networks with Noise Uncertainty

This correspondence investigates a joint spectrum sensing scheme in cognitive radio (CR) networks with unknown and dynamic noise variance. A novel Bayesian solution is proposed to recover the dynamic noise variance and detect the occupancy of primary frequency band simultaneously. The states of primary users are detected based on particle filtering technology, and then the noise parameters are tracked by using finite-dimensional statistics for each particle based on marginalized adaptive particle filtering. Simulation results are provided to validate that the proposed method can improve the sensing performance significantly and target the dynamic noise variance accurately.

ETPL WC - 028	Energy-Efficient Management of Cognitive Radio Terminals with Quality-Based Activation

In cooperative cognitive radio systems (CRSs), where battery-powered cognitive radio terminals (CTs) frequently sense and report primary user's (PU's) existence to exploit a spectrum hole, energy efficiency (EE) is a challenging design issue. To improve EE in CRSs, letting only some of the CTs be active in sensing and reporting [called a quality-based activation (QBA)] is proposed in this letter. With QBA, CTs that have good channel quality in a data channel (DCH) as well as a reporting channel (RCH) are allowed to sense and report. A possible drawback of such conditional activation is that it could limit the participation of CTs in a scheduling procedure, and hence, may result in losing certain system throughput. Throughput and EE of CRSs with the proposed QBA are investigated and it is shown, with numerical examples, that QBA does not decrease the throughput and provides significant improvement in EE.

ETPL WC - 029	A Distributed Learning Automata Scheme for Spectrum Management in Self-Organized Cognitive Radio Network

We propose a distributed Learning Automata (LA) for spectrum management problem in Cognitive Radio (CR) networks. The objective is to design intelligent Secondary Users (SUs) which can interact with the RF environment and learn from its different responses through the sensing. It is assumed there is no prior information about the Primary Users (PUs) and other SUs activities while there is no information exchange among SUs. Each SU is empowered with an LA which operates in the RF environment with different responses. That is, the SUs are considered as agents in a self-organized system which select one channel as an action and receive different responses from the environment based on how much their selected actions are favourable or unfavourable. Using these responses, SUs control their accesses to the channels for appropriate spectrum management with the objective to incur less communication delay, less interference with PUs, and less interference with other SUs. The proposed LA-based distributed algorithm is investigated in terms of asymptotic convergence and stability. Simulation results are provided to show the performance of the proposed scheme in terms of SUs' waiting times, interference with other SUs, and the number of interruptions by PUs during their transmissions, and fairness.

ETPL WC - 030	Construction and Analysis of Shift-Invariant, Asynchronous-Symmetric Channel-Hopping Sequences for Cognitive Radio Networks

Besides designing channel-hopping (CH) sequences, finding good methods of communication rendezvous is important for improving spectral efficiency and alleviating traffic load of cognitive radio (CR) networks. In this paper, new asynchronous-symmetric CH sequences are constructed and their (channel overlap, even-channel-use, and pairwise shift invariance) properties are investigated. Their operations in three transmission scenarios involving different basic collision-avoidance mechanisms are analyzed and compared in terms of maximum time-to-rendezvous, rendezvous-success (RS) rate, and RS variance. This paper shows that the new sequences have shorter period, larger cardinality, and smaller RS variations than other CH sequences, thus supporting greater number of secondary users and more frequent and uniform rendezvous in the CR networks.

ETPL WC - 031	Design and development of KNACKSAT: First fully in-house developed satellite in Thailand

This study presents conceptual design and development of a 1U CubeSat satellite named KNACKSAT (KmutNb Academic Challenge of Knowledge SATellite). The minimum requirements of the satellite are that its maximum dimensions are 10 cm × 10 cm × 10 cm and a maximum mass is 1.3 kilogram. The components used are commercial off-the-shelf. The main functions of the satellite include transmitting housekeeping data through a continues wave, sending uplink commands and downlink data through radio frequencies, and taking images by using a CMOS camera. KNACKSAT consists of seven subsystems: (1) Electrical Power Subsystem, (2) Camera Subsystem (or Payload), (3) Structure Subsystem, (4) Command and Data Handling Subsystem, (5) Attitude Determination and Control Subsystem, (6) Communication Subsystem and (7) Deployment Control Subsystem. The satellite is planned to be launched into a sun-synchronous orbit in 2017. Some results of a functional integration test of the subsystems through TableSat are also presented in this paper.

ETPL WC - 032	Performance Analysis for Two-Way Network-Coded Dual-Relay Networks with Stochastic Energy Harvesting

In this paper, we consider an energy harvesting (EH) two-way (TW) dual-relay network, including one non-EH relay and one EH relay equipped with a finite-sized battery. In the network, a space-time transmission protocol with space-time network coding (STNC) is designed, and an optimal transmission policy for the EH relay is proposed by using a stochastic solar EH model. In this optimal policy, the long-term paired-wise error probability (PEP) of the system is minimized by adapting the EH relay's transmission power to the knowledge of its current battery energy, channel fading status and causal solar EH information. The designed problem is formulated as a Markov decision process (MDP) framework, and the conditional capability of the contribution to PEP by the EH relay is adopted as the reward function. We uncover a monotonic and limited difference structure for the expected total discounted reward. Further, a non-conservative property and a monotonic structure of the optimal policy are revealed. Based on the optimal policy and its special structures, the expectation, lower and upper bounds, and asymptotic approximation of the PEP are computed and an interesting result on the system diversity performance is revealed, i.e., the full diversity order can be achieved only if the EH capability index, a metric to quantify the EH node's capability of harvesting and storing energy, approaches to infinity; otherwise, the EH diversity order is only equal to one, and the coding gain of the network is increasing with the EH capability index at this time. Furthermore, a full diversity criterion for the EH TW dual-relay network is proposed.

ETPL WC - 033	Utility Maximization for Two-Way AF Relaying Under Rate Outage Constraints

In this paper, we focus on maximizing the system utility (e.g., the weighted sum-rate, weighted geometric mean rate, and the harmonic mean rate) of a two-way relay network (TWRN) from the outage probability perspective; a TWRN has multiple relay nodes and two terminal nodes.We assume amplify-and- forward relaying with analog network coding protocol and half-duplex transmission with perfect channel state information at the receiver ends and channel distribution information at the transmitter ends.We derive the approximated closed-form for the outage probability of a TWRN; however, the approximated outage constraints lead to a non-convex structure for the considered problem. Based on successive convex approximation technique, we obtain near optimal solution for the non-convex problem. Moreover, we derive closed-form solutions for the maximization problem for the weighted sum rate maximization problem for a TWRN with a single relay node and two relay nodes under individual power constraints. Our simulation results demonstrate the accuracy of our outage probability approximation model and the advantages of our algorithm over naive methods of full and uniform power allocation.

ETPL WC - 034	Staleness Bounds and Efficient Protocols for Dissemination of Global Channel State Information

This paper considers the problem of achieving global channel knowledge throughout a fully-connected packetized wireless network with time-varying channels. While the value of channel state information at the transmitter (CSIT) is now well-known, there are many scenarios in which it is helpful to have additional channel knowledge beyond conventional CSIT, e.g., cooperative communication systems. The overhead required for global CSI knowledge can be significant, particularly in time-varying channels where the quality of channel estimates is dominated by the “staleness” of the CSI. Nevertheless, the fundamental limits and feasibility of tracking global CSI throughout a network have not been sufficiently studied. This paper presents a framework for analyzing the staleness of protocols that estimate and disseminate CSI to all nodes in a fully-connected network. Fundamental bounds on achievable staleness are derived, and efficient dissemination protocols are developed which achieve these limits. The results provide engineering guidelines on the feasibility of tracking global CSI as a function of network size, the size and composition of the packets, packet error rate, and channel coherence time.

ETPL WC - 035	Traffic Management for Heterogeneous Networks with Opportunistic Unlicensed Spectrum Sharing

This paper studies how to maximize the per-user-based throughput in an M-tier heterogeneous wireless network (HetNet) by optimally managing traffic flows among the access points (APs) in the HetNet. The APs in the first M −1 tiers can use the licensed spectrum at the same time whereas they share the unlicensed spectrum with the APs in the Mth tier by the proposed opportunistic CSMA/CA protocol. We characterize the statistical property of the cell load and channel access probability of each AP using a general AP association scheme. For an AP in each tier, the tight bounds on its mean spectrum efficiencies in the licensed and unlicensed spectra are derived in a low-complexity form for general random channel gain and AP association weight models and they can give some insights on how channel gains, AP association weights and void AP probabilities affect the mean spectrum efficiencies. We define the per-user link throughput and per-user network throughput based on the derived the mean spectrum efficiencies and maximize them by proposing the decentralized and centralized traffic management schemes for the APs in the first M − 1 tiers under the constraint that the per-user link throughput of the tier-M APs must be above some minimum required value. Finally, a numerical example of coexisting LTE and WiFi networks is provided to validate our derived results and findings.

ETPL WC - 036	Multi-Resolution Codebook and Adaptive Beam forming Sequence Design for Millimeter Wave Beam Alignment

Millimeter wave (mmWave) communication is expected to be widely deployed in fifth generation (5G) wireless networks due to the substantial bandwidth available for licensed and unlicensed use at mmWave frequencies. To overcome the higher path loss observed at mmWave bands, most prior work focused on the design of directional beamforming using analog and/or hybrid beamforming techniques in large-scale multiple-input multiple-output (MIMO) systems. Obtaining potential gains from highly directional beamforming in practical systems hinges on sufficient levels of channel estimation accuracy, where the problem of channel estimation becomes more challenging due to the substantial training overhead needed to sound all directions using a high-resolution narrow beam. In this paper, we consider the design of multi-resolution beamforming sequences to enable the system to quickly search out the dominant channel direction for single-path channels. The resulting design generates a multilevel beamforming sequence that strikes a balance between minimizing the training overhead and maximizing beamforming gain, where a subset of multilevel beamforming vectors is chosen adaptively to maximize the average data rate within a constrained time. We propose an efficient method to design a hierarchical multi-resolution codebook utilizing a Butler matrix, i.e., a generalized discrete Fourier transform (DFT) matrix. Numerical results show the effectiveness of the proposed algorithm.

ETPL WC - 037	Time-Domain Turbo Equalization for Single-Carrier Generalized Spatial Modulation

In this paper, low-complexity time-domain turbo equalization (TDTE) detectors based upon the soft-interference-cancellation (SIC)-aided minimum mean-square error (MMSE) criterion are proposed for single carrier (SC) generalized spatial modulation (GSM) (SC-GSM) systems. First, a symbol-by-symbol (SS)-aided TDTE (SS-TDTE) detector for application to the small-scale GSM systems is proposed, where the zero symbols are considered as constellation points when performing SIC. Then, vector-by-vector (VV)-aided TDTE (VV-TDTE) detectors for application to larger-scale antenna systems are introduced, where the GSM symbol is treated as an entire vector when performing SIC. As for the proposed VV-TDTE detectors, in addition, different time-varying filter coefficients are designed, in order to strike a flexible trade-off between complexity and performance. By relying upon extrinsic information transfer (EXIT) chart analysis, we show that the proposed TDTE detectors are capable of providing considerable bit error rate (BER) performance gains over existing TDTE detectors and over the classic frequency-domain equalization (FDE) based MMSE detector, especially for the unbalanced antenna configurations.

ETPL WC - 038	On the Degrees of Freedom of the Symmetric Multi-Relay MIMO Y Channel

Abstract—In this paper, we study the degrees of freedom (DoF) of the symmetric multi-relay multiple-input multipleoutput (MIMO) Y channel, where three user nodes, each with M antennas, communicate via K geographically separated relay nodes, each with N antennas. For this model, we establish a general DoF achievability framework based on linear precoding and post-processing methods. The framework poses a nonlinear problem with respect to user precoders, user post-processors and relay precoders. To solve this problem, we adopt an uplinkdownlink asymmetric strategy, where the user precoders are designed for signal alignment and the user post-processors are used for interference neutralization. With the user precoder and post-processor designs fixed as such, the original problem then reduces to a problem of relay precoder design. To address the solvability of the system, we propose a general method for solving matrix equations. Together with the techniques of antenna disablement and symbol extension, an achievable DoF of the considered model is derived for an arbitrary setup of (K,M,N). We show that for $K\geq 2$, the optimal DoF is achieved for $MN\in[0,\max\{3K\sqrt{3},1\})\cup[3k+9K2-12k\sqrt{6},\infty)$. We also show that the uplink-downlink asymmetric design proposed in this paper considerably outperforms the conventional approach based on uplink-downlink symmetry.

ETPL WC - 039	Spatio-temporal Interference Correlation and Joint Coverage in Cellular Networks

This paper provides an analytical framework with foundations in stochastic geometry to characterize the spatiotemporal interference correlation as well as the joint coverage probability at two spatial locations in a cellular network. In particular, modeling the locations of cellular base stations (BSs) as a Poisson Point Process (PPP), we study interference correlation at two spatial locations ℓ 1 and ℓ 2 separated by a distance v, when the user follows closest BS association policy at both spatial locations and moves from 1 to ℓ 2 . With this user displacement, two scenarios can occur: i) the user is handed off to a new serving BS at ℓ 2 , or ii) no handoff occurs and the user is served by the same BS at both locations. After providing intermediate results such as probability of handoff and distance distributions of the serving BS at the two user locations, we use them to derive exact expressions for spatio-temporal interference correlation coefficient and joint coverage probability for any distance separation v. We also study two different handoff strategies: i) handoff skipping, and ii) conventional handoffs, and derive the expressions of joint coverage probability for both strategies. The exact analysis is not straightforward and involves a careful treatment of the neighborhood of the two spatial locations and the resulting handoff scenarios. To provide analytical insights, we also provide easy-to-use expressions for two special cases: i) static user (v=0) and ii) highly mobile user (v→∞) As expected, our analysis shows that the interference correlation and joint coverage probability decrease with increasing v.

ETPL WC - 040	Exploiting Direct Links in Multiuser Multirelay SWIPT Cooperative Networks with Opportunistic Scheduling

In this paper, we analyze the downlink outage performance of opportunistic scheduling in dual-hop cooperative networks consisting of one source, multiple radio-frequency (RF) energy harvesting relays, and multiple destinations. To this end, two low-complexity, suboptimal, yet efficient, relay-destination selection schemes are proposed, namely direct links plus opportunistic channel state information (CSI)-based selection (DOS) scheme and direct links plus partial CSI-based selection (DPS) scheme. Considering three relaying strategies, i.e., decode-and-forward (DF), variable-gain amplify-and-forward (VG-AF), and fixed-gain amplify-and-forward (FG-AG), the performance analysis in terms of outage probability (OP) is carried out for each selection scheme. For the DF and VG-AF strategies, exact analytical expressions and tight closed-form approximate expressions for the OP are derived. For the FG-AF strategy, an exact closed-form expression for the OP is provided. Additionally, we propose a gradient-based search method to find the optimal values of the power-splitting ratio that minimizes the attained OPs. The developed analysis is corroborated through Monte- Carlo simulation. Comparisons with the optimal joint selection scheme are performed and it is shown that the proposed schemes significantly reduce the amount of channel estimations while achieving comparable outage performance. In addition, regardless of relaying strategy used, numerical results show that the DOS scheme achieves full diversity gain, i.e., M + K, and the DPS scheme achieves the diversity gain of M + 1, where M and K are the numbers of destinations and relays, respectively.

ETPL WC - 041	Phase Retrieval Motivated Nonlinear MIMO Communication with Magnitude Measurements

This paper proposes a multiuser magnitude-only (MO-)MIMO, whose base station (BS) acquires quantized magnitudes of the complex baseband signals through envelop detectors and low-resolution ADCs. Consequently, MO-MIMO enjoys much lower circuit power and cost in comparison to the conventional MIMO. Because the phase information is unavailable, all the existing MIMO baseband algorithms cannot be applied into MO-MIMO. Therefore, two types of channel estimators and multiuser detectors are constructed by firstly categorizing the channel estimation (CE) and multiuser detection (MUD) problems as a quantized phase retrieval (PR) problem, and then solving the latter by developing two methods under the framework of generalized approximate message passing (GAMP). The first method directly applies GAMP to solve the quantized PR problem by exploiting the probability relationships between the quantized magnitude measurements and unknown complex signals. The second method iterates between the missing phase estimation and signal recovery, where the latter calls for GAMP to handle a linear mixing problem with quantized observations. The developed estimators and detectors call for matrix-vector multiplications (MVMs) and nonlinear function calculations as the most complex operations, handle the nonlinear quantization loss specially, and exploit the signal prior probability distributions. Finally, their effectiveness is validated experimentally.

ETPL WC - 042	Fault Tolerant Key Generation and Secure Spread Spectrum Communication

A fundamental characteristic of wireless communications are in their broadcast nature, which allows accessibility of information without placing restrictions on a user's location. However, accessibility also makes wireless communications vulnerable to eavesdropping. In this context, our paper presents a two-part secure information transmission system. The first part makes use of reciprocity in wireless channels to allow for two asynchronous transceivers to obtain a pair of similar keys. Moreover, a unique augmentation - called strongest path cancellation (SPC) - is applied to the keys. In the second part, the concept of artificial noise is introduced to spread spectrum systems. Keys generated in the first part are used in the spread spectrum system and artificial noise is added to enhance the security of the communications. Two attacks on the proposed security solution are evaluated. First, an adversary following the same steps as the legitimate users is considered. Here, simulation and experimentation results show that SPC provides a boost to security against this type of adversary. The second attack studies an adversary with significant blind detection capabilities. Our observations on this attack indicate that when ample amount of artificial noise can be used, two legitimate parties can communicate multiple information symbols per key.

ETPL WC - 043	On Physical Layer Security: Weighted Fractional Fourier Transform based User Cooperation

In this paper, we propose a novel user cooperation scheme based on weighted fractional Fourier transform (WFRFT), to enhance the physical (PHY) layer security of wireless transmissions against eavesdropping. Specifically, instead of dissipating additional transmission power for friendly jamming, by leveraging the features of WFRFT, the information bearing signal of cooperators can create an identical "artificial noise" effect at the eavesdropper while causing no performance degradation on the legitimate receiver. Further, to form the cooperation set in an autonomous and distributed manner, we model WFRFT-based PHY-layer security cooperation problem as a coalitional game with non-transferable utility. A distributed merge-and-split algorithm is devised to facilitate the autonomous coalition formation to maximize the security capacity while accounting for the cooperation cost in terms of power consumption. We analyze the stability of the proposed algorithm and also investigate how the network topology efficiently adapts to the mobility of intermediate nodes. Simulation results demonstrate that the WFRFT-based user cooperation scheme leads to a significant performance advantage, in terms of secrecy ergodic capacity, compared with the conventional security-oriented user cooperation schemes, such as relay-jamming and cluster-beamforming.

ETPL WC - 044	Robust Beam forming Design in C-RAN with Sigmoidal Utility and Capacity-Limited Backhaul

In the paper, we study the robust beamforming design in cloud radio access networks where remote radio heads (RRHs) are connected to a cloud server that performs signal processing and resource allocation in a centralized manner. Different from traditional approaches adopting a concave increasing function to model the utility of a user, we model the utility by a sigmoidal function of the signal-to-interference-plus-noise ratio (SINR) to capture the diminishing utility returns for very small and very large SINRs in real-time applications (e.g. video streaming). Our objective is to maximize the aggregate utility of the users while taking into account the imperfection of channel state information (CSI), limited backhaul capacity, and minimum quality of service requirements. Because of the sigmoidal utility function and some of the constraints, the formulated problem is non-convex. To efficiently solve the problem, we introduce a maximum interference constraint, transform the CSI uncertainty constraints into linear matrix inequalities, employ convex relaxation to handle the backhaul capacity constraints, and exploit the sum-of-ratios form of the objective function. This leads to an efficient resource allocation algorithm which outperforms several baseline schemes and closely approaches a performance upper bound for large CSI uncertainty or large number of RRHs.

ETPL WC - 045	Analytical Characterization of Device-to-Device and Cellular Networks Coexistence

This paper presents a new analytical framework based on stochastic geometry for the characterization of the reciprocal impact of device-to-device (D2D) communications and an underlaid cellular network in terms of coverage probability. We consider a random number of device-to-device (D2D) groups where the devices of each group are distributed according to different spatial distributions to model users' behavior. The effect of power control, users' spatial distribution, shadowing and random base stations (BS) deployment are accounted for in the analysis and closed form expressions for coverage probability for both cellular and D2D networks are derived. The validity of the framework developed is assessed via simulation in the numerical results where the effect of key system parameters as well as devices spatial distribution on cellular and D2D coverage is investigated and the amount of the traffic that could be offloaded through D2D communications is studied.

ETPL WC - 046	Simultaneous Sensing and Transmission for Cognitive Radios with Imperfect Signal Cancellation

In conventional cognitive radio systems, the secondary user employs a "listen-before-talk" paradigm, where it senses if the primary user is active or idle, before it decides to access the licensed spectrum. However, this method faces challenges with the most important being the reduction of the secondary user's throughput, as no data transmission takes place during the sensing period. In this context, the idea of simultaneous spectrum sensing and data transmission is proposed. The present work studies a system model where this concept is obtained through the collaboration of the secondary transmitter with the secondary receiver. First, the secondary receiver decodes the signal from the secondary transmitter, subsequently, removes it from the total received signal and then, carries out spectrum sensing in the remaining signal in order to decide about the presence/absence of the primary user. Different from the existing literature, this paper takes into account the imperfect signal cancellation, evaluating how the decoding errors affect the sensing reliability and derives the analytical expressions for the probability of false alarm. Finally, numerical results are presented illustrating the accuracy of the proposed analysis.

ETPL WC - 047	Multilevel Coding Scheme for Integer-Forcing MIMO Receiver with Binary Codes

An integer-forcing (IF) linear multiple-input multiple-output (MIMO) receiver has recently been proposed, which is theoretically shown to achieve near-capacity with almost the same complexity as that of conventional linear receivers. The key idea is that the receiver attempts to directly decode integerlinear combinations of codewords. To ensure that this sumdecoding operation is feasible, in previous works, lattice codes over Z_q were employed. Although those codes can attain good theoretical performance, however, its implementation complexity can be considerably high in practice, especially when q is large to support high-order modulations. In this paper, we propose a practical multilevel coding scheme for IF MIMO, in which multilevel encoding composed of binary linear codes $(q=2)$ in conjunction with the natural mapping is employed on the transmitter side and multistage decoding adapted to the IF operation is employed on the receiver side. The performance of the proposed scheme is extensively evaluated both analytically and numerically, showing that the gain of IF over conventional receivers is indeed achievable in practical settings with almost the same complexity. Our results imply that the proposed IF MIMO can be an attractive solution for the 5G communications due to its ability of supporting high spectral efficiency with low complexity.

ETPL WC - 048	Performance of SIM-MDPSK FSO Systems with Hardware Imperfections

This paper studies the error performance of free-space optical (FSO) systems, employing subcarrier intensity modulation (SIM) with M-ary differential phase-shift keying (MDPSK). Novel analytical expressions for the symbol error probability (SEP) are derived, based on the Fourier series approach. The irradiance fluctuations of the received optical signal are modeled by considering both Gamma-Gamma atmospheric turbulence and pointing errors. In addition, hardware imperfections of DPSK demodulator, as the phase noise of local oscillator at the receiver, are taken into account. It is illustrated that the phase noise significantly degrades the system performance, especially when the optical signal transmission is impaired by weak atmospheric turbulence and weak pointing errors effect. Furthermore, the phase noise results in an unrecoverable error-rate floor, which is an important limiting factor for SIM-DPSK FSO systems.

ETPL WC - 049	State-Dependent Bandwidth Sharing Policies for Wireless Multirate Loss Networks

We consider a reference cell of fixed capacity in a wireless cellular network while concentrating on next-generation network architectures. The cell accommodates new and handover calls from different service-classes. Arriving calls follow a random or quasi-random process and compete for service in the cell under two bandwidth sharing policies: i) a probabilistic threshold (PrTH) policy, or ii) the multiple fractional channel reservation (MFCR) policy. In the PrTH policy, if the number of inservice calls (new or handover) of a service-class exceeds a threshold (different between new and handover calls), then an arriving call of the same service-class is accepted in the cell with a predefined state-dependent probability. In the MFCR policy, a real number of channels is reserved to benefit calls of certain service-classes; thus a service priority is introduced. The cell is modeled as a multirate loss system. Under the PrTH policy, call-level performance measures are determined via accurate convolution algorithms, while under the MFCR policy, via approximate but efficient models. Furthermore, we discuss the applicability of the proposed models in 4G/5G networks. The accuracy of the proposed models is verified through simulation. Comparison against other models reveals the necessity of the new models and policies.

ETPL WC - 050	Joint Transceiver Design for Full-Duplex Cloud Radio Access Networks with SWIPT

This work studies joint transceiver design for a fullduplex (FD) cloud radio access network (C-RAN) with simultaneous wireless information and power transfer (SWIPT). In the considered network, a number of FD remote radio heads (RRHs) receive information from uplink users, while transmitting both information and energy to a set of half-duplex (HD) downlink users with power splitting receivers. We aim to minimize the total power consumption with both uplink-downlink quality of service (QoS) constraints and energy harvesting (EH) constraints. The resulting problem is challenging because various design parameters such as the transceiver beamformers, the uplink transmit power and the receive power splitting ratios are tightly coupled in the constraints. Four different solution approaches are proposed for the joint transceiver design problem, each one leading to a different numerical algorithm. In particular, a block coordinate descent (BCD) method is proposed, and by exploiting the problem structure, we prove that the algorithm converges to a Karush-Kuhn-Tucker (KKT) solution, despite the coupling of various design variables in the constraints. Simulation results validate the effectiveness of the proposed algorithms as compared with the traditional HD scheme.

ETPL WC - 051	Symbol-Level Multiuser MISO Precoding for Multi-level Adaptive Modulation

Symbol-level precoding is a new paradigm for multiuser multiple-antenna downlink systems which aims at creating constructive interference among the transmitted data streams. This can be enabled by designing the precoded signal of the multiantenna transmitter on a symbol level, taking into account both channel state information and data symbols. Previous literature has studied this paradigm for Mary phase shift keying (MPSK) modulations by addressing various performance metrics, such as power minimization and maximization of the minimum rate. In this paper, we extend this to generic multi-level modulations i.e. Mary quadrature amplitude modulation (MQAM) by establishing connection to PHY layer multicasting with phase constraints. Furthermore, we address adaptive modulation schemes which are crucial in enabling the throughput scaling of symbol-level precoded systems. In this direction, we design signal processing algorithms for minimizing the required power under per-user signal to interference noise ratio (SINR) or goodput constraints. Extensive numerical results show that the proposed algorithm provides considerable power and energy efficiency gains, while adapting the employed modulation scheme to match the requested data rate.

ETPL WC - 052	Enhancing Multiuser MIMO through Opportunistic D2D Cooperation

We propose a cellular architecture that combines multiuser MIMO (MU-MIMO) downlink with opportunistic use of unlicensed ISM bands to establish device-to-device (D2D) cooperation. The architecture consists of a physical-layer cooperation scheme based on forming downlink virtual MIMO channels through D2D relaying, and a novel resource allocation strategy for such D2D-enabled networks. We prove the approximate optimality of the physical-layer scheme, and demonstrate that such cooperation boosts the effective SNR of the weakest user in the system, especially in the many-user regime, due to multiuser diversity. To harness this physical-layer scheme, we formulate the cooperative user scheduling and relay selection problem using the network utility maximization framework. For such a cooperative network, we propose a novel utility metric that jointly captures fairness in throughput and the cost of relaying in the system. We propose a joint user scheduling and relay selection algorithm, which we prove to be asymptotically optimal. We study the architecture through system-level simulations over a wide range of scenarios. The highlight of these simulations is an approximately 6x improvement in data rate for cell-edge (bottom fifth-percentile) users (over the state-of-the-art) while still improving the overall throughput, and taking into account various system constraints.

ETPL WC - 053	A Novel Mirror-Aided Non-imaging Receiver for Indoor 2×2 MIMO Visible Light Communication Systems

Indoor visible light communication (VLC) systems are now possible because of advances in light emitting diode and laser diode technologies. These lighting technologies provide the foundation for multiple-input multiple-output (MIMO) data transmission through visible light. However, the channel matrix can be strongly correlated in indoor MIMO-VLC systems, preventing parallel data streams from being decoded. Here, in 2×2 MIMO-VLC systems, we describe a mirror diversity receiver (MDR) design that reduces the channel correlation by both blocking the reception of light from one specific direction and improving the channel gain from light from another direction by utilizing a double-sided mirror deployed between the receiver's photodetectors. We report on the channel capacity of the MDR system and the optimal height of its mirrors in terms of maximum channel capacity. We also derived analytic results on the effect of rotation on MDR's performance. Based on numerical and experimental results, we show that the double-sided mirror has both constructive and destructive effects on the channel matrix. Our design can be used with previously described non-imaging systems to improve the performance of indoor VLC systems.

ETPL WC - 054	Ergodic Fading MIMO Dirty Paper and Broadcast Channels: Capacity Bounds and Lattice Strategies

A multiple-input multiple-output (MIMO) version of the dirty paper channel is studied, where the channel input and the dirt experience the same fading process with channel state information at the receiver (CSIR). This represents settings where signal and interference sources are co-located, such as in the broadcast channel. First, a variant of Costa's dirty paper coding (DPC) is presented, whose achievable rates are within a constant gap to capacity for all signal and dirt powers. Additionally, a lattice coding and decoding scheme is proposed, whose decision regions are independent of the channel realizations. Under Rayleigh fading, the gap to capacity of the lattice coding scheme vanishes with the number of receive antennas, even at finite SNR. Thus, although the capacity of the fading dirty paper channel remains unknown, this work shows it is not far from its dirt-free counterpart. The insights from the dirty paper channel directly lead to transmission strategies for the two-user MIMO broadcast channel (BC), where the transmitter emits a superposition of desired and undesired (dirt) signals with respect to each receiver. The performance of the lattice coding scheme is analyzed under different fading dynamics for the two users, showing that high-dimensional lattices achieve rates close to capacity.

ETPL WC - 055	An Experimental Evaluation of Switched Combining Based Macro-Diversity for Wearable Communications Operating in an Outdoor Environment

This paper investigates the potential improvement in signal reliability for outdoor wearable communications channels operating at 868 MHz using switched combining based macro-diversity. In this study, a number of different macro-diversity configurations consisting of two and four base stations were considered to help mitigate the impact of body shadowing upon a wearable node which was located on the central chest region of an adult male. During the field measurements, five different walking movements were performed and then analyzed to investigate the efficacy of using macro-diversity. It was found that all of the considered switched combining schemes including switch-and-stay combining (SSC), switch-and-examine combining (SEC) and SEC with post-examining selection (SECps) provided a worthwhile signal improvement when an appropriate switching threshold was adopted. The maximum diversity gain obtained in this study was found to be 19.5 dB when using four-base station SECps. The diversity gain, the number of path examinations and the number of path switches between base stations for the switched combiner output varied according to the determined switching threshold, highlighting the importance of the selection of an appropriate threshold level. Furthermore, the performance/complexity trade off is demonstrated. Finally, the fading behavior at the output of the switched diversity combiners was then characterized using the diversity specific equations developed under the assumption of independent and non-identically distributed Nakagami- m fading channels. Over all of the measurement scenarios considered in this study, the theoretical models provided an adequate fit to the fading observed at the output of the virtual switched combiner.

ETPL WC - 056	Cross-Layer Performance of Downlink Dynamic Cell Selection with Random Packet Scheduling and Partial CQI Feedback in Wireless Networks with Cell Sleeping

In this paper, we consider a coordinated multipoint (CoMP) dynamic cell selection (DCS) transmission scheme for serving sleeping cell user equipments (UEs). According to this DCS scheme, packets of UEs in a sleeping cell are randomly forwarded to the potential active base stations (BSs) by the packet serving gateway (PSG) and UEs in the sleeping cell dynamically select their serving BS from these active BSs. We model the system as a fork/join (F/J) queuing system and develop a cross-layer analytical model that considers the time varying nature of the channels, channel scheduling mechanism, partial channel quality information (CQI) feedback, cell selection mechanism, bursty packet arrivals and packet scheduling mechanism. The developed analytical model can be used to measure various packet level performance parameters such as packet loss probability (PLP) and queuing delay while accounting for out-of-sequence packet delivery. We validate the accuracy of the developed analytical model via simulations and we compare the performance of the DCS scheme under consideration with the conventional fixed cell selection scheme and with the state-of-the-art DCD scheme. Presented numerical results show that the DCS scheme under consideration significantly improves the PLP performance. Queuing delay performance, on the other hand, depends on the system and operating parameters.

ETPL WC - 057	Millimeter-Wave Channel Estimation Based on Two-Dimensional Beamspace MUSIC Method

Due to the spatial sparsity caused by the severe propagation loss, the millimeter-wave (mm-wave) channel estimation can be performed by estimating the directions and gains of the paths that have significant power. In this paper, we apply the beamspace two-dimensional multiple signal classification (MUSIC) method to estimate the path directions (the angles of departure and arrival) and use the least-squares method to estimate the path gains. Different from its element-space counterpart, the beamspace MUSIC method may exhibit spectrum ambiguity caused by the beamformers. In this paper, we therefore analyze the sufficient conditions on the beamformers under which the MUSIC spectrum has no ambiguity which also leads to the maximum number of resolvable path directions. Moreover, based on the uniform linear array with half-wavelength spacing, we show that the discrete Fourier transform (DFT) beamformers, which are naturally analog and often employed in the mm-wave communication systems with hybrid precoding structure, can avoid the spectrum ambiguity and maximize the number of resolvable path directions. Simulation results demonstrate that the proposed two-dimensional beamspace MUSIC mm-wave channel estimator significantly outperforms existing estimators that are based on beam training and sparse recovery; and in the meantime, it requires much less training slots than these existing methods.

ETPL WC - 058	Angle and Delay Estimation for 3D Massive MIMO/FD-MIMO Systems Based on Parametric Channel Modeling

In order to meet the challenge of increasing data-rate demand as well as the form factor limitation of the base station, 3D massive MIMO (Multiple-Input Multiple-Output) technology has been introduced as one of the enabling technologies for the fifth generation (5G) mobile cellular systems. In 3D massive MIMO systems, a base station (BS) will rely on the uplink sounding signals from mobile stations to figure out the spatial information for downlink MIMO operations. Accordingly, multidimensional parameter estimation of a MIMO channel becomes crucial for such systems to realize the predicted capacity gains.

ETPL WC - 059	Joint Fronthaul Multicast Beamforming and User-Centric Clustering in Downlink C-RANs

The cloud radio access network (C-RAN) is deemed as a cost-effective architecture to exploit the capacity benefit of densely deployed radio access points. The low-latency fronthaul data transmission from the central processor to small-cell base stations (SBSs) is a key requirement in C-RANs, for which conventional wired fronthaul links will be cost-prohibitive and also inconvenient. Therefore, scalable and low-cost wireless fronthaul solutions have drawn much attention in both industry and academia. In this paper, we propose to adopt the multicast beamforming strategy over fronthaul links to deliver each user's message to a cluster of SBSs selected according to the user-centric clustering scheme, which then adopts the joint beamforming technique to cooperatively transmit the signal to the target users. Some approximate techniques are applied to obtain a tractable formulation for this mixed integer nonlinear programming (MINLP) problem, and an iterative algorithm based on the block coordinate update method is proposed accordingly. Then, a binary search based algorithm is developed to preserve the sparsity of beamformers due to the relaxation of the discrete clustering function with the continuous exponential function. Extensive simulation results are provided to show the performance of the proposed algorithms in terms of convergence, power consumption and weighted sum rate.

ETPL WC - 060	Fundamental Storage-Latency Tradeoff in Cache-Aided MIMO Interference Networks

Caching is an effective technique to improve user perceived experience for content delivery in wireless networks. Wireless caching differs from traditional web caching in that it can exploit the broadcast nature of wireless medium and hence opportunistically change the network topologies. This paper studies a cache-aided MIMO interference network with 3 transmitters each equipped with M antennas and 3 receivers each with N antennas. With caching at both the transmitter and receiver sides, the network is changed to hybrid forms of MIMO broadcast channel, MIMO X channel, and MIMO multicast channels. We analyze the degrees of freedom (DoF) of these new channel models using practical interference management schemes. Based on the collective use of these DoF results, we then obtain an achievable normalized delivery time (NDT) of the network, an information-theoretic metric that evaluates the worst-case delivery time at given cache sizes. The obtained NDT is for arbitrary M, N and any feasible cache sizes. It is shown to be optimal in certain cases and within a multiplicative gap of 3 from the optimum in other cases. The extension to the network with arbitrary

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