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Contents

MIMO

An Investigative Study of Cyclic Prefix-free MC-CDMA Arrayed-MIMO Communication Systems - 1 -
Ho Huat Peh (Imperial College, United Kingdom)
Athanassios Manikas (Imperial College London, United Kingdom)
Tjeng Thiang Tjhung (Institute for Infocomm Research, Singapore)
Lawrence Wong (National University of Singapore, Singapore)

On the Performance of SIC-MMSE Turbo Equalization with Iterative Channel Estimation for UCCI-Limited MIMO-ISI Systems - 7 -
Tarik Ait-Idir (ENST Bretagne, France)
Samir Saoudi (ENST-Bretagne, France)

DCT-based Channel Estimation Method for MIMO-OFDM Systems Using Phase Shifted Pilot Sequences - 12 -
Shaopeng Feng (Beijing University of Posts and Telecommunications, P.R. China)
Weiling Wu (Beijing University of Posts and Telecommunications, P.R. China)

Channel Estimation Algorithms for Uplink OFDMA Tiles - 16 -
Marie-Eve Grandmaison (École de technologie supérieure, Canada)
François Gagnon (Ecole de Technologie Superieure, Canada)

Wireless Networks I

QoS Dashboard: Translation of User Inputs to Networking Strategies - 20 -
Wenjing Wang (University of Central Florida, USA)
Mainak Chatterjee (University of Central Florida, USA)
Kevin Kwiat (Air Force Research Lab, USA)

Energy-Aware Topology Control in Heterogeneous Wireless Multi-Hop Networks - 25 -
Rui Zhang (University of South Florida, USA)
Miguel Labrador (University of South Florida, USA)

Quantifying the Gains of an Optimal Information Model to Facilitate Policy Based QoS in Heterogeneous Communications Networks - 31 -
Jerome Sonnenberg (Harris Corporation, USA)

Energy-Aware Communication Module Selection through ZigBee Paging for Ubiquitous Wearable Computers with Multiple Radio Interfaces - 37 -
Su Min Kim (Korea Advanced Institute of Science and Technology, Korea)
Jo Woon Chong (Korea Advanced Institute of Science and Technology, Korea)
Byoung Hoon Jung (Korea Advanced Institute of Science and Technology, Korea)
Min Suk Kang (Korea Advanced Institute of Science and Technology, Korea)
Dan Keun Sung (Korea Advanced Institute of Science and Technology, Korea)

Shortcut Tree Routing in ZigBee Networks - 42 -
Taehong Kim (Information and Communications University, Korea)
Daeyoung Kim (Information and Communications University, Korea)
Noseong Park (Information and Communications University, Korea)
Seong-eun Yoo (Information and Communications University, Korea)
Tomás Sánchez López (Information and Communications University, Korea)

Wireless Sensor Networks I

Anchor-Based Geographic Routing for Sensor Networks Using Projection Distance - 48 -
Gang Zhao (University of Louisville, USA)
Xiangqian Liu (University of Louisville, USA)
Min-Te Sun (Auburn University, USA)
Priority-based Routing for Solar-Powered Wireless Sensor Networks - 53 -
Donggeon Noh (Seoul National University, Korea)
Junu Kim (University of Seoul National University, Korea)
Junho Lee (Seoul National University, Korea)
Dongeun Lee (Seoul National University, Korea)
Hyentaek Kwon (Seoul National University, Korea)
Heonshik Shin (Seoul National University, Korea)
Dynamic Context Networks of Wireless Sensors and RFID tags - 59 -
Tomás Sánchez López (Information and Communications University, Korea)
Daeyoung Kim (Information and Communications University, Korea)
Kyungseon Min (Korea Telecom, Daejeon, South Korea)
Joonho Lee (Korea Telecom, Daejeon, South Korea)
A Routing Algorithm for Mobile Multiple Sinks in Large-Scale Wireless Sensor Networks - 65 -
Mujdat Soyturk (Istanbul Technical University, Turkey)
Turgay Altilar (Istanbul Technical University, Turkey)
DA-MLAR-ODTP: Directional Antenna Multi-path Location Aided Routing with On Demand Transmission Power - 71 -
Sanjaya Gajurel (Case Western Reserve University, USA)
Behnam Malakooti (Case Western Reserve University, USA)
Limin Wang (Bell Laboratories, USA)

Wireless Sensor Networks II

Analysis of Energy Consumption in Clustered Wireless Sensor Networks - 77 -
Bolian Yin (University of Missouri, USA)
Hongchi Shi (Univ. of Missouri, USA)
Yi Shang (University of Missouri, USA)
Genetic Algorithm Based Approach for Extending the Lifetime of Two-Tiered Sensor Networks - 83 -
Shamsul Wazed (School of Computer Science, University of Windsor, Canada)
Ataul Bari (School of Computer Science, University of Windsor, Canada)
Arunita Jaekel (School of Computer Science, University of Windsor, Canada)
Subir Bandyopadhyay (School of Computer Science, University of Windsor, Canada)
Adaptive Lifetime Maximization Strategies for Wireless Sensor Networks - 88 -
Ines Slama (National Institute of Telecommunication, France)
Badii Jouaber (National Institute of Telecommunication, France)
Djamal Zeghlache (National Institute of Telecommunication, France)
Map-based Adaptive Positioning in Wireless Sensor Networks - 93 -
Ahmed Ahmed (Zagazig University, Egypt, Egypt)
Hongchi Shi (Univ. of Missouri, USA)
Yi Shang (University of Missouri, USA)
An Operational Model for Mobile Target Tracking in Wireless Sensor Networks - 99 -
Marc Bui (EPHE, LaISC - 41 rue G. Lussac, 75005 Paris, France)
Jean Frédéric Myoupo (Université de Picardie Jules Verne, France)
Idrissa Sow (University of picardie-Jules Verne, Amiens, France)

UWB

Ultra Wideband (UWB) Interference on UMTS Receivers - 105 -
Gustavo Nader (Mobile Satellite Ventures, Reston, USA)
Annamalai Annamalai (Virginia Polytechnic Institute and State University, Blacksburg, USA)
A Method for the Analysis of the impact of UWB interference on the Performance of UMTS Networks - 109 -
Gustavo Nader (Mobile Satellite Ventures, Reston, USA)
Annamalai Annamalai (Virginia Polytechnic Institute and State University, Blacksburg, USA)
Impact of Error weight distribution in MB-OFDM based UWB system with spreading - 115 -
Nidhi Panday (Kansas State University, USA)
Bala Natarajan (Kansas State University, USA)
Joint TOA and AOA Estimation of UWB Signal Using Time Domain Smoothing - 120 -
Naohiko Iwakiri (Tokyo Denki University, Japan)
Takehiko Kobayashi (Tokyo Denki University, Japan)
Performance of G-RAKE Receiver in DS-CDMA Ultra-Wideband Systems - 126 -
Tuncer Baykas (University of Ottawa, Canada)
Abbas Yongacoglu (University of Ottawa, Canada)
Mohamed Siala (Sup'Com, Tunisia)

Link Layer Techniques

A New Protocol to Mitigate the Unheard RTS/CTS Problem in Networks with Switched Beam Antennas - 129 -
Valli RamMohan (Drexel University, USA)
Harish Sethu (Drexel University, USA)
Madhusudan Hosaagrahara (Drexel University, USA)
Kapil Dandekar (Drexel University, USA)
Time Slot Assignment for Maximum Bandwidth in a Mobile Ad Hoc Network - 135 -
Jianping Li (The University of Tokyo, Japan)
Yasushi Wakahara (Information Technology Center, The University of Tokyo, Japan)
Optimization of IEEE 802.11e Access Class Parameters with Cross-layer Approach - 141 -
Ivano Alocci (CNIT - University of Siena, Italy, Italy)
Giovanni Giambene (University of Siena, Italy)
Yevgeni Koucheryavy (Tampere University of Technology, Finland)
Call Admission Control in Wireless DS-CDMA Systems using Actor-Critic Reinforcement Learning - 146 -
Pitipong Chanloha (Suranaree University of Technology, Thailand)
Wipawee Usaha (Suranaree University of Technology, Thailand)
Design of Adaptive Modulation and Coding Scheme for Truncated HARQ - 151 -
Si Hyun Park (Korea University, Korea)
Jinwoo Kim (Korea University, Korea)
Kang Chung Gu (School of Electrical Engineering, Korea University, Korea)

Poster Session I

A WLAN/WMAN Dual Mode Transceiver System for Indoor/Outdoor Application - 156 -

Kukjin Chun (Seoul National University, Korea)
Joonyeop Lee (Seoul National University, Korea)
Ji-Hyuk Kim (Seoul National University, Korea)
Hyeon Cheol Kim (Seoul National University, Korea)
Kwang-Jun Yoon (Future Communication Inc., Korea)
Young-Ill Kim (Samsung Advanced Institute of Technology, Korea)
In-Sang Song (Samsung Advanced Institute of Technology, Korea)

A Countermeasure Against Frequent Attacks Based on the Blom-scheme in Ad Hoc Sensor Networks - 160 -
Shiuh-Jeng Wang (Central Police University, Taiwan)
Yuh-Ren Tsai (National Tsing Hua University, Taiwan)
Jhoong-Wei Chan (National Tsing Hua University, Taiwan)

Performance analysis of IEEE 802.11n under different STBC rates using 64-QAM - 164 -
Anastasios Gravalos (Brunel University, United Kingdom)
Marios Hadjinicolaou (Brunel University, United Kingdom)
Qiang Ni (Brunel University, United Kingdom)

A Route Planning Method Using Cost Map for Mobile Sensor Nodes - 169 -
Masaki Nakamiya (Osaka university, Japan)
Yasue Kishino (Osaka University, Japan)
Tsutomu Terada (Osaka University, Japan)
Shojiro Nishio (Osaka University, Japan)

Power Conservation in Zigbee Networks Using Temporal Control - 175 -
Arun Viswanathan (University of Colorado at Colorado Springs, USA)
Terrance Boult (University of Colorado at Colorado Springs, USA)

RSS Self-calibration Protocol for WSN Localization - 181 -
Jihoon Kang (Information and Communications University, Korea)
Daeyoung Kim (Information and Communications University, Korea)
Youngsoo Kim (Information and Communications University, Korea)

Multicast in Wireless Sensor Networks - the next step - 185 -
Jorge Silva (University of Coimbra, Portugal)
T. Camilo (University of Coimbra, Portugal)
A. Rodrigues (University of Coimbra, Portugal)
M. Silva (University of Coimbra, Portugal)
F. Gaudêncio (University of Coimbra, Portugal)
F. Boavida (University of Coimbra, Portugal)

Improving EDGE for rural environments through channel allocation for voice and data traffic - 191 -
Carlos Ramírez-Casañas (Technical University of Catalonia, Spain)
Josep Paradells (Technical University of Catalonia, Spain)
Sònia Mansilla (Technical University of Catalonia, Spain)

Optimal Allocation of Bandwidth and Power Resources to OFDMA VoIP Channels - 196 -
Patrick Hosein (Huawei Technologies, USA)

Adaptive Interference-Aware Multi-Channel Clustering Algorithm in a ZigBee Network in the Presence of WLAN Interference - 200 -
Min Suk Kang (Korea Advanced Institute of Science and Technology, Korea)
Jo Woon Chong (Korea Advanced Institute of Science and Technology, Korea)
Hyesun Hyun (KAIST, Korea)
Su Min Kim (Korea Advanced Institute of Science and Technology, Korea)
Byoung Hoon Jung (Korea Advanced Institute of Science and Technology, Korea)
Dan Keun Sung (Korea Advanced Institute of Science and Technology, Korea)

PPM-based Orthogonal Space-Time Coding for IR-UWB MIMO channels affected by Poisson-distributed Multipaths - 206 -
Enzo Baccarelli (University of Rome ""La Sapienza"", Italy)
Mauro Biagi (University of Rome "La Sapienza", Italy)

Cristian Pelizzoni (University of Rome "La Sapienza", Italy)
Nicola Cordeschi (Infocom Dept. University of Rome "La Sapienza", Italy)
Ubiquitous Wearable Computer (UWC)-Aided Coexistence Algorithm in an Overlaid Network Environment of WLAN and Zigbee Networks - 212 -
Byoung Hoon Jung (Korea Advanced Institute of Science and Technology, Korea)
Jo Woon Chong (Korea Advanced Institute of Science and Technology, Korea)
Seong Hoon Jeong (Korea Advanced Institute of Science and Technology, Korea)
Ho Young Hwang (Korea Advanced Institute of Science and Technology, Korea)
Su Min Kim (Korea Advanced Institute of Science and Technology, Korea)
Min Suk Kang (Korea Advanced Institute of Science and Technology, Korea)
Dan Keun Sung (Korea Advanced Institute of Science and Technology, Korea)
A Profile-Based Peer-to-Peer RSS Information Distribution - 218 -
André Baumgart (University of Mannheim, Germany)
Hartwig Knapp (University of Mannheim, Germany)
Pascal Sütterlin (University of Mannheim, Germany)
Martin Schader (University of Mannheim, Germany)
A Novel Weighted Cooperative Routing Algorithm Based on Distributed Relay Selection - 224 -
Chao Chen (Nanjing University of Posts and Telecommunications, P.R. China)
Baoyu Zheng (Nanjing Univ. of Posts and Telecommunications, P.R. China)
Xianjing Zhao (Nanjing University of Posts And Telecomm., P.R. China)
Zhenya Yan (Nanjing University of Posts & Telecommunications, P.R. China)
PCPP: Private Computing on Public Platforms A New Paradigm in Public Computing - 230 -
Thomas Morris (Southern Methodist University, USA)
Suku Nair (Southern Methodist University, USA)
Semi-Proactive RSVP Extension for Wireless Mobile Networks - 236 -
Franco Tommasi (University of Lecce, Italy)
Simone Molendini (University of Lecce, Italy)
Andrea Tricco (University of Lecce, Italy)
Elena Scialpi (University of Lecce, Italy)
An ICI-free synchronization algorithm in MIMO-OFDM system - 242 -
Zhangyong Ma (Intel, P.R. China)
Xiaoyun WU (Intel Communication Technology Lab (Beijing), P.R. China)
Wenwu Zhu (Intel China, P.R. China)
Transmit Diversity Method with User’s Power Constraint for Distributed Antenna System - 247 -
ShenFa Liu (Beijing University of Posts and Telecommunications, P.R. China)
ZhiQiang He (Beijing University of Posts and Telecommunications, P.R. China)
Weiling Wu (Beijing University of Posts and Telecommunications, P.R. China)

Wireless Sensor Networks III

Stateless Data Flow Approach with Void Avoidance for Wireless Ad Hoc and Sensor Networks - 252 -
Mujdat Soyturk (Istanbul Technical University, Turkey)
Turgay Altilar (Istanbul Technical University, Turkey)
SEA-MAC: A Simple Energy Aware MAC Protocol for Wireless Sensor Networks for Environmental Monitoring Applications - 258 -
Miguel Erazo (University of Puerto Rico at Mayaguez, Puerto Rico)
Yi Qian (University of Puerto Rico at Mayaguez, Puerto Rico)
An Energy-Efficient Approach to Scheduling in Wireless Sensor Networks - 263 -
Lin Fang (University of California, Irvine, USA)
Rui J.P. de Figueiredo (University of California, Irvine, USA)
Distributed Low Power Scheduling in Wireless Sensor Networks - 268 -

Taehong Kim (Information and Communications University, Korea)
Noseong Park (Information and Communications University, Korea)
Poh Kit Chong (Information and Communications University, Korea)
Jongwoo Sung (Information and Communications University, Korea)
Daeyoung Kim (Information and Communications University, Korea)

MC-CDMA

Near-Optimal Multiuser Detection in Asynchronous MC-CDMA via the Ant Colony Approach - 274 -
Samer Hijazi (Kansas State University, USA)
Bala Natarajan (Kansas State University, USA)
An Efficient Multi-User Detection Scheme For Overloaded Group-Orthogonal MC-CDMA Systems - 280 -
Ping Wang (McGill University, Canada)
Tho Le-Ngoc (McGill University, Canada)
Generating Spreading Codes for MC-CDMA with Desirable Crest Factor and Error Weight Distribution - 285 -
Hassan Raza (Kansas State University, USA)
Justin Dyer (Kansas State University, USA)
Bala Natarajan (Kansas State University, USA)
Utility-Based Energy-Efficient Power Control for Multi-Carrier DS/CDMA - 291 -
Lin Fang (University of California, Irvine, USA)
Rui J.P. de Figueiredo (University of California, Irvine, USA)

Wireless Networks II

Optimized Cooperative Diversity for a Three-Node Decode-and-Forward Relay Channel - 296 -
Kai Kit Wong (University College London, United Kingdom)
Elsheikh Elsheikh (University of Hull, United Kingdom)
Key Factor and Interaction for Network Performance in Mobile Ad Hoc Networks - 302 -
Yiming Wang (University of Bristol, United Kingdom)
Dritan Kaleshi (University of Bristol, United Kingdom)
Michael Barton (University of Bristol, United Kingdom)
Jianhua He (University of Bristol, United Kingdom)
Li Li (University of Bristol, United Kingdom)
Alistair Munro (University of Bristol, United Kingdom)
Zhong Fan (Toshiba Research Europe, United Kingdom)
Designing Wireless Networks by Test Point Reduction - 307 -
Natthapol Pongthaipat (University of Pittsburgh, USA)
Joseph Kabara (University of Pittsburgh, USA)
Virtual Mobile Backbones for Wireless Ad-hoc Networks with the support of Directional Array Antennas - 311 -
Jeong-Gil Ko (Korea University, Korea)
Ji-Hun Ha (Korea University, Korea)
Bum-Sik Park (Hoseo University, Korea)
Seung-Goo Lee (Hoseo University, Korea)
Hak-Lim Ko (Hoseo University, Korea)
Grid Based Pervasive Distributed Storage - 316 -
Diego Arias (University of Puerto Rico, Puerto Rico)
John Sanabria (University of Puerto Rico, Puerto Rico)
Wilson Rivera (University of Puerto Rico, Puerto Rico)

High Capacity VoIP Services in 802.11 Networks - 321 -
Manjari Chhawchharia (Motorola India Private Limited, India)
Atanu Guchhait (Motorola Labs, India)

Mobility Modeling and Routing

New metrics to evaluate mobility models properties - 327 -
Fabrice Theoleyre (Lab. LSR - UMR CNRS 5526, France)
Rabih Tout (INSA Lyon, France)
Fabrice Valois (INSA Lyon, France)
Modeling of mobility and groups in inter-vehicular MANET-based networks - 333 -
Juan Carlos Cano Escriba (Universidad Politecnica de Valencia, Spain)
Carlos Calafate (Polytechnic University of Valencia, Spain)
Pietro Manzoni (Universidad Politecnica de Valencia, Spain)
Chai Keong Toh (University of Hong Kong, China)
Local Maximum Avoidance with Correlated Street Blocking for MAP-based Geographic Routing in VANETs - 338 -
Tuan Luong (Nanyang Technological University, Singapore)
Boon-Chong Seet (Nanyang Technological University, Singapore)
Bu Sung Lee (Nanyang Technological University, Singapore)
3-D Localized Position-Based Routing with Nearly Certain Delivery in Mobile Ad Hoc Networks - 344 -
George Kao (Concordia University, Canada)
Thomas Fevens (Concordia University, Canada)
Jaroslav Opatrny (Concordia University, Canada)
An Unified Kalman Tracking Technique for Wireless Location Systems - 350 -
Po-Hsuan Tseng (National Chiao Tung University, Taiwan)
Chao-Lin Chen (National Chiao Tung University, Taiwan)
Kai-Ten Feng (National Chiao Tung University, Taiwan)

Wireless Multimedia

Motion Based Reference-Free Quality Estimation for H.264/AVC Video Streaming - 355 -
Michal Ries (Vienna Univeristy of Technology, Austria)
Olivia Nemethova (Vienna Univeristy of Technology, Austria)
Markus Rupp (Vienna Univeristy of Technology, Austria)
Quality Assessment of an Adaptive Filter for Artifact Reduction in Mobile Video Sequences - 360 -
Ulrich Engelke (Blekinge Institute of Technology, Sweden)
Andreas Rossholm (Ericsson Mobile Platforms AB, Sweden)
Hans-Juergen Zepernick (Blekinge Institute of Technology, Sweden)
Benny Lövström (Blekinge Institute of Technology, Sweden)
Quality Evaluation in Wireless Imaging Using Feature-Based Objective Metrics - 367 -
Ulrich Engelke (Blekinge Institute of Technology, Sweden)
Hans-Juergen Zepernick (Blekinge Institute of Technology, Sweden)
Enterprise Library Management for Digital Media with Dynamic Media Synthesis - 373 -
Bill Bodin (IBM CIO Innovations, USA)
Ann Marie Maynard (IBM Research, USA)
Trigger Management Mechanisms - 378 -

Jukka Mäkelä (VTT Technical Research Centre of Finland, Finland)
Kostas Pentikousis (VTT Technical Research Centre of Finland, Finland)

Bluetooth

Performance Improvement through Diversity Reception for Bluetooth in the Presence of Interference - 384 -
Barbara Mavì Masini (WiLab, University of Bologna, Italy)
Andrea Conti (IEIIT/CNR Univ. of Bologna, ENDIF Univ. of Ferrara, Italy)
Oreste Andrisano (University of Bologna, Italy)
Dual Channel Transmission for Coexistence of Bluetooth Piconets with Multi-Slot Packets - 389 -
Jingli Li (University of Louisville, USA)
Xiangqian Liu (University of Louisville, USA)
Xiaoli Ma (Georgia Institute of Technology, USA)
Energy efficiency of different data transmission methods in IEEE 802.15.4: study and improvement - 395 -
Liang Cheng (Georgia State University, USA)
Anu Bourgeois (GSU, USA)
Distributed Tuplespace and Location Management - an Integrated Perspective using Bluetooth - 401 -
Anders Fongen (The Norwegian School of Information Technology, Norway)
Christian Larsen (The Norwegian School of Information Technology, Norway)
Gheorghita Ghinea (Brunel University, United Kingdom)
Simon Taylor (Brunel University, United Kingdom)

Wireless Security

Efficient and Secure Multicast in WirelessMAN - 407 -
Matthew Ginley (University of South Carolina, USA)
Sen Xu (University of South Carolina, USA)
Chin-Tser Huang (University of South Carolina, USA)
Manton Matthews (University of South Carolina, USA)
A Multi-agent Approach Toward the Security Analysis of the 802.11i Handshake Protocol - 413 -
Ratan Guha (University of Central Florida, USA)
Zeeshan Furqan (University of Central Florida, USA)
Shahabuddin Muhammad (University of Central Florida, USA)
Active Cache Based Defense against DoS Attacks in Wireless Mesh Network - 419 -
Lakshmi Santhanam (University of Cincinnati, USA)
Deepti Nandiraju (University of Cincinnati, USA)
Nagesh Nandiraju (University of Cincinnati, USA)
Dharma Agrawal (UNIVERSITY OF CINCINNATI, USA)
Performance Study of a Secure Routing Protocol in Wireless Mobile Ad Hoc Networks - 425 -
Mohamad Alsaadi (University of Puerto Rico at Mayaguez, Puerto Rico)
Yi Qian (University of Puerto Rico at Mayaguez, Puerto Rico)

New Applications and Services

MSM: A Middleware Architecture for Enhancing Interaction with Mobile Services - 431 -
Qusay Mahmoud (University of Guelph, Canada)
Eyhab Al-Masri (University of Guelph, Canada)
Middleware for multi-client and multi-server mobile applications - 437 -
Bruno Rocha (Federal University of Minas Gerais, Brazil)
Cristiano Rezende (Federal University of Minas Gerais, Brazil)
Antonio A.F. Loureiro (Federal University of Minas Gerais, Brazil)
Wireless System for Patient Home Monitoring - 442 -
Maija Marttila-Kontio (University of Kuopio, Finland)
Marko Hassinen (University of Kuopio, Finland)
Challenges of SIP in internet connected MANETs - 447 -
Marcel Castro (Karlstad University, Sweden)
Andreas J. Kassler (Karlstad University, Sweden)
A Framework for supporting VoIP Services over the Downlink of an OFDMA Network - 453 -
Patrick Hosein (Huawei Technologies, USA)

Channel Issues

Repeatability of Received Signal Level Measurements in GSM Cellular Networks - 459 -
Nenad Mijatovic (Florida Institute of Technology, USA)
Ivica Kostanic (Florida Institute of Technology, USA)
Adding Angle of Arrival Modality to Basic RSS Location Management Techniques - 464 -
Eiman Elnahrawy (Rutgers University, USA)
John-Austen Francisco (Rutgers University, USA)
Richard Martin (Rutgers University, USA)
Adding Motion Capability to the Spatial Channel Model - 470 -
Alfonso Rodriguez (Motorola, Mexico)
Steve Jasper (Motorola Labs, USA)
Doug Reed (Motorola, USA)
NAES: A Natural Adaptive Exponential Smoothing for Channel Prediction in WLANs - 476 -
Jeandro Bezerra (Universidade Estadual do Ceará, Brazil)
Rudy Braquehais (Universidade Estadual do Ceará, Brazil)
Filipe Roberto (Universidade Estadual do Ceará, Brazil)
Jorge Castro e Silva (UECE, Brazil)
Marcial Fernandez (UECE, Brazil)
Thelmo de Araujo (State University of Ceará, Brazil)
Joaquim Celestino (Universidade Estadual do Ceará, Brazil)
Pablo Ximenes (University of Puerto Rico at Mayaguez, USA)
Delay-Tolerant Space-Time Block Codes for Asynchronous Cooperative Relaying - 481 -
Mohamed Oussama Damen (University of Waterloo, Canada)
A. Roger Hammons Jr. (APL, Johns Hopkins University, USA)

Poster Session II

Performance Analysis of Three Gated Service Polling Scheme on Wireless Network - 487 -

Yan Li (Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, China)
Guangxi Zhu (Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, China)

Analysis of Tracking Methods for Wireless Indoor Localization - 492 -
Juan Besada (Universidad Politecnica de Madrid, Spain)
Ana Bernardos (Universidad Politecnica de Madrid, Spain)
Paula Tarrío (Universidad Politecnica de Madrid, Spain)
Jose Casar (Universidad Politecnica de Madrid, Spain)

Improved Hamming Code for Error Detection and Correction - 498 -
Udaya Kumar (B.N.M.Institute of Technology, India)
Bangalore Umashankar (B.N.M.Institute of Technology, India)

Enhancing Performance of Space-Time Parameter Estimation in DS-CDMA Arrays - 501 -
Rui Wu (University of Jyväskylä, Finland)
Tapani Ristaniemi (University of Jyväskylä, Finland)

Mobile Sensor Management For Target Tracking - 506 -
Suhinthan Maheswararajah (University of Melbourne, Australia)
Saman Halgamuge (The University of Melbourne, Australia)

Integrating Perceptual, Device and Location Characteristics for Wireless Multimedia Transmission - 511 -
Tacha Serif (Brunel University, United Kingdom)
Gheorghita Ghinea (Brunel University, United Kingdom)
Anders Fongen (The Norwegian School of Information Technology, Norway)

EUTRAN Uplink Performance - 515 -
Timo Lunttila (Nokia Networks, Finland)
Jari Lindholm (Nokia Networks, Finland)
Kari Pajukoski (Nokia, Finland)
Esa Tiirola (Nokia, Finland)
Antti Toskala (Nokia Networks, Finland)

Performance Analysis of Angle Modulated MQAM Transmission Techniques - 520 -
Viktor Zaharov (Polytechnic University of Puerto Rico, Puerto Rico)
Alexander Kokhanov (Ukraine State Academy of Communications, Ukraine)

Coordinator Rotation via Domatic Partition in Self-Organizing Sensor Networks - 525 -
Rajiv Misra (Indian Institute of Technology, India)
Chittaranjan Mandal (Indian Institute of Technology, Kharagpur, India)
Ratan Guha (University of Central Florida, USA)

Hierarchical and fault-tolerant data aggregation in wireless sensor networks - 531 -
Mikel Larrea (University of the Basque Country, Spain)
Cristian Martín (University of the Basque Country, Spain)
Jose Javier Astrain (Universidad Publica de Navarra, Spain)

Opportunistic Radio and Licensed Users Coexistence in Cellular Networks - 537 -
Artur Pereira (Instituto de Telecomunicações - Universidade de Aveiro, Portugal), Atílio Gameiro, (Departamento de Electrónica & Telecomunicações, Universidade de Aveiro, Portugal)

Performance of Ultra-Wideband Transmission over 60GHz WPAN Channel - 543 -
Wei Li (France Telecom Research and Development, South San Francisco, CA 94080)

Wireless Sensor Networks as Agents for Intelligent Control of Distributed Energy Resources - 547 -
Joshua Wall (CSIRO Energy Technology, Australia)
Glenn Platt (CSIRO Energy Technology, Australia)
Geoffrey James (CSIRO ICT Centre, Australia)
Philip Valencia (CSIRO ICT Autonomous Systems Laboratory, Australia)

A methodology to enhance media policing over IMS Networks - 552 -
Jithesh Sathyan (Infosys Technologies Limited, India)
Naveen Unni (Infosys Technologies Limited, India)
Ad Hoc Network Performance Dynamics- a Study - 557 -
Heloisa Peixoto de Barros Pimentel (Unicamp- State University of Campinas, Brazil, Brazil)
José Antônio Martins
(Fundação CPqD, Campinas, Brazil)
VLSI Architectures for Turbo Decoding Message Passing Using Min-Sum for Rate-Compatible Array LDPC Codes - 561 -
Kiran Gunnam (Texas A&M, USA)
Weihuang Wang (Texas A&M University, USA)
Gwan Choi (Texas A&M University, College Station, USA)
Mark Yeary (University of Oklahoma, USA)

Pervasive Computing

Ultrasonic Power and Data Link for Wireless Implantable Applications - 567 -
Satu Arra (Tampere University of Technology, Finland)
Jarkko Leskinen (University of Kuopio, Finland)
Janne Heikkilä (University of Kuopio, Finland)
Jukka Vanhala (Tampere University of Technology, Finland)
Always Best Located, a Pervasive Positioning System - 572 -
Lionel Reyero (Institut National de la Recherche Scientifique, Canada)
Gilles Y. Delisle (International Institute of Telecommunications, Canada)
Minimizing Location Uncertainty in Deployment of Access Points - 577 -
Peng Zhuang (University of Misouri-Columbia, USA)
Qingguo Wang (University of Missouri-Columbia, USA)
Yi Shang (University of Missouri, USA)
Hongchi Shi (Univ. of Missouri, USA)
Enabling real-time fleet route planning and execution in a pervasive transportation environment - 583 -
Samik Ghosh (University Of Texas at Arlington, USA)
Nilendu G. Jani (ZMS Technologies Inc., Richardson TX, USA)
Sajal Das (University Of Texas at Arlington, USA)
A wearable IEEE 802.15.4 system for logistics scenarios - 589 -
Fabio Bonizzi (Università di Modena e Reggio Emilia, Italy)
Lucio Sedoni (Embit, Italy)
Davide Sganzerla (Embit, Italy)
Umberto Manzoli (embit co.ltd., Italy)
Paolo Pavan (Università di Modena e Reggio Emilia, Italy)

PHY Layer Issues

Implementing a Vector RLS Smart Antenna Beamformer Using Xilinx System Generator - 594 -
Viktor Zaharov (Polytechnic University of Puerto Rico, Puerto Rico)
Angel Gonzalez (Polytechnic University of Puerto Rico, Puerto Rico)
James Acosta (Polytechnic University of Puerto Rico, Puerto Rico)
Marvi Teixeira (Polytechnic University of Puerto Rico, Puerto Rico)
An Iterative Power Allocation Scheme for Spread Spectrum Wireless Systems - 600 -
Caimu Tang (Tut Systems, Lake Oswego, OR 97035, USA)
Anthony Chronopoulos (The University of Texas at San Antonio, USA)
Paul Cotae (University of Texas at San Antonio, USA)

Symbol Mapping Diversity and Power Adjustment for High Speed Downlink Packet Access (HSDPA) - 606 -
Mikael Gidlund (Access Research Group, Acreo AB, SE-824 12 Hudiksvall, Sweden)
Channel-Change Games for Highly Interfering Spectrum-Agile Wireless Networks - 611 -
Roli Wendorf (Pace University, USA)
Howard Blum (Pace University, USA)
A Short-burst Synchronization Method for Narrowband Wireless Communication Systems - 617 -
Takafumi Fujita (NTT Corporation, Japan)
Daisei Uchida (NTT, Japan)
Yosuke Fujino (NTT Corporation, Japan)
Osamu Kagami (NTT, Japan)
Kazuji Watanabe (NTT, Japan)

Wireless Sensor Networks IV

Analysis of the Performance of Decentralized Sensor Network with Correlated Observations - 622 -
Nithya Gnanapandithan (Kansas State University, USA)
Bala Natarajan (Kansas State University, USA)
Multiple-Objective Metric for Placing Multiple Base Stations in Wireless Sensor Networks - 627 -
Soo Kim (Korea University, Korea)
Jeong-Gil Ko (Korea University, Korea)
Jongwon Yoon (Korea University, Korea)
Heejo Lee (Korea University, Korea)
Performance of Parallel Decentralized Sensor Network with Decision Feedback - 632 -
Sunitha Kopparthi (Kansas State University, USA)
Bala Natarajan (Kansas State University, USA)

$$\underline{x}\left[n\right]=\sum_{j=1}^{K_u}\sum_{k=1}^{N_{sc}}\beta_{jk}\underline{S}_j\otimes\left(\begin{array}{c}\left(\mathbb{J}^T\right)^L\mathbb{J}^{l_j}\underline{\mathrm{f}}_k\left[l_j\right]\overline{\underline{S}}_j^H\left(\underline{\gamma}\left[k\right]\odot\underline{\mathrm{a}}\left[n-1\right]\right)+\\ \mathbb{J}^{l_j}\underline{\mathrm{f}}_k\left[l_j\right]\overline{\underline{S}}_j^H\left(\underline{\gamma}\left[k\right]\odot\underline{\mathrm{a}}\left[n\right]\right)\\ +\left(\mathbb{J}\right)^L\mathbb{J}^{l_j}\underline{\mathrm{f}}_k\left[l_j\right]\overline{\underline{S}}_j^H\left(\underline{\gamma}\left[k\right]\odot\underline{\mathrm{a}}\left[n+1\right]\right)\end{array}\right)+\underline{n}\left(t\right) \tag{9}$$

$$\begin{aligned}\underline{x}\left[n\right]\quad=\quad&\underbrace{\left[\mathbf{H}_1\mathbf{B}_1,\ldots,\mathbf{H}_j\mathbf{B}_j,\ldots,\mathbf{H}_{K_u}\mathbf{B}_{K_u}\right]\left(\underline{1}_{K_u}\otimes\mathbb{C}\right)}_{\mathbb{H}_{desired}}\underline{\mathrm{a}}\left[n\right]+\\&\underbrace{\left[\mathbf{H}_{1,prev}\mathbf{B}_1,\ldots,\mathbf{H}_{j,prev}\mathbf{B}_j,\ldots,\mathbf{H}_{K_u,prev}\mathbf{B}_{K_u}\right]\left(\underline{1}_{K_u}\otimes\mathbb{C}\right)}_{\mathbb{H}_{ISI,prev}}\underline{\mathrm{a}}\left[n-1\right]+\\&\underbrace{\left[\mathbf{H}_{1,next}\mathbf{B}_1,\ldots\mathbf{H}_{1j,next}\mathbf{B}_{1j},\ldots,\mathbf{H}_{K_u,next}\mathbf{B}_{K_u}\right]\left(\underline{1}_{K_u}\otimes\mathbb{C}\right)}_{\mathbb{H}_{ISI,next}}\underline{\mathrm{a}}\left[n+1\right]+\underline{n}\left[n\right]\end{aligned} \tag{14}$$

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a path delay of l sample periods. In addition,

$$\mathbb{J}=\begin{bmatrix}\underline{0}_{2L-1}^T & 0\\ \mathbb{I}_{2L-1} & \underline{0}_{2L-1}\end{bmatrix} \tag{8}$$

is used to model the delay l on the column vector $\underline{\mathrm{f}}_k$. For instance, if $\mathbb{J}^l$ pre-multiplies $\underline{\mathrm{f}}_k$, it downshifts the elements of $\underline{\mathrm{f}}_k$ by l elements. On the other hand, pre-multiplying $\underline{\mathrm{f}}_k$ with $\left(\mathbb{J}^T\right)^l$ upshifts the column vector by l elements. Using $\underline{\mathrm{f}}_k\left[l\right]$ and $\mathbb{J}$ as defined above in Equations 7 and 8, Equation 6 is rewritten as shown in Equation 9.

However, Equation 9 can be further re-expressed as shown in Equation 10.

$$\underline{x}\left[n\right]=\sum_{j=1}^{K_u}\left(\begin{array}{c}\mathbf{H}_{j,prev}\mathbf{B}_j\mathbb{C}\underline{\mathrm{a}}\left[n-1\right]\\ +\mathbf{H}_j\mathbf{B}_j\mathbb{C}\underline{\mathrm{a}}\left[n\right]\\ +\mathbf{H}_{j,next}\mathbf{B}_j\mathbb{C}\underline{\mathrm{a}}\left[n+1\right]\end{array}\right)+\underline{n}\left[n\right] \tag{10}$$

where

$$\mathbf{H}_j=\underline{S}_j\otimes\left(\mathbb{J}^{l_j}\left[\underline{\mathrm{f}}_1\left[l_j\right],\ldots,\underline{\mathrm{f}}_k\left[l_j\right],\ldots,\underline{\mathrm{f}}_{N_{sc}}\left[l_j\right]\right]\right), \tag{11}$$

$$\mathbf{H}_{j,prev}=\left(\mathbb{I}_N\otimes\left(\mathbb{J}^T\right)^L\right)\mathbf{H}_j,$$

$$\mathbf{H}_{j,next}=\left(\mathbb{I}_N\otimes\mathbb{J}^L\right)\mathbf{H}_j$$

$$\begin{aligned}\mathbf{B}_j\ &=\ \mathrm{diag}\left(\underline{\beta}_j\right)\otimes\overline{\underline{S}}_j^H, \\ \underline{\beta}_j\ &=\ \left[\beta_{j1},\ldots,\beta_{jk},\ldots,\beta_{jN_{sc}}\right]^T\end{aligned} \tag{12}$$

and

$$\begin{aligned}\mathbb{C}\ &=\ \left[\underline{\gamma}_1\otimes\underline{e}_1,\ldots,\underline{\gamma}_i\otimes\underline{e}_i,\ldots,\underline{\gamma}_{\overline{N}}\otimes\underline{e}_{\overline{N}}\right]\\ &=\ \left[\underline{c}_1,\ldots,\underline{c}_i,\ldots,\underline{c}_{\overline{N}}\right]\end{aligned} \tag{13}$$

$\underline{c}_i=\underline{\gamma}_i\otimes\underline{e}_i$ and $\underline{e}_i$ is a $\overline{N}\times 1$ column vector with 1 at the i^{th} position and 0s elsewhere. In Equation 12, $\mathbf{B}_j$ models the effective fading coefficients on each subcarrier from each antenna element in the transmitter to the reference point of the receiver antenna array. Equation 10 can now be expressed in a vector format in Equation 14. The first term in Equation 14 represents the desired signal component contributed by the current symbol vector, while the second and third terms represent the ISI components due to the previous and next symbol vectors, respectively.

C. Receiver Weights Formulation

In this paper, three types of receivers have been considered to compare their relative performances in the proposed system. At point F in Fig. 1, the vector $\underline{x}\left[n\right]$ (from Equation 14) is pre-multiplied by the matrix $\mathbb{W}^H$ to obtain the decision variable vector $\underline{d}\left[n\right]$, given by

$$\underline{d}\left[n\right]=\mathbb{W}^H\underline{x}\left[n\right] \tag{15}$$

The vector $\underline{d}\left[n\right]$ is then multiplexed and passed to the decision device to obtain the received channel symbol stream.

1) Subspace Based Receiver: For the proposed subspace based receiver, the channel matrix of the unwanted signals can be formed as

$$\widehat{\mathbb{H}}_{ISI}=\left[\widehat{\mathbb{H}}_{ISI,prev}\quad\widehat{\mathbb{H}}_{ISI,next}\right] \tag{16}$$

where $\widehat{\mathbb{H}}_{ISI,prev}$ and $\widehat{\mathbb{H}}_{ISI,next}$ represent the estimates of the ISI components of the previous and next symbols respectively, as given in Equation 14. The complement projection operator of the ISI signal subspace can then be formed by

$$\mathbb{P}_{ISI}^{\perp}=\mathbb{I}_{2NL}-\widehat{\mathbb{H}}_{ISI}\left(\widehat{\mathbb{H}}_{ISI}^H\widehat{\mathbb{H}}_{ISI}\right)^{-1}\widehat{\mathbb{H}}_{ISI}^H \tag{17}$$

Thus, for the subspace based receiver, the weight matrix, $\mathbb{W}$, at point F in Fig. 1, is given by

$$\mathbb{W}_{subspace}=\mathbb{P}_{ISI}^{\perp}\widehat{\mathbb{H}}_{desired}\left(\widehat{\mathbb{H}}_{desired}^H\mathbb{P}_{ISI}^{\perp}\widehat{\mathbb{H}}_{desired}\right)^{-1} \tag{18}$$

$\widehat{\mathbb{H}}_{desired}$ represents the estimate of the desired signal component of the current symbol vector.

2) Minimum Mean Squared Error (MMSE) Receiver: For the MMSE receiver, the weight matrix, $\mathbb{W}$, at point F in Fig. 1, is given by

$$\mathbb{W}_{mmse}=\widehat{\mathbb{H}}\left(\widehat{\mathbb{H}}^H\widehat{\mathbb{H}}+\sigma_n^2\mathbb{I}_{2NL}\right)^{-1} \tag{19}$$