WICAT WORKSHOP

ON

SINGLE CARRIER FREQUENCY DIVISION MULTIPLE ACCESS (SC-FDMA)

MARCH 13, 2009

POLYTECHNIC INSTITUTE OF

NEW YORK UNIVERSITY

BROOKLYN, NY 11201

Technical Program Chair: Dr. Hyung G. Myung, Qualcomm/Flarion

Advisory Board: Prof. Henry Bertoni & Prof. David J. Goodman, Polytechnic Institute of NYU

Sponsored and organized by Wireless Internet Center for Advanced Technology (WICAT), a National Science Foundation Industry/University Cooperative Research Center at Polytechnic Institute of NYU

WORKSHOP AGENDA

9:00	Registration & opening remarks - Dr. Hyung G. Myung, Qualcomm/Flarion
9:30	Single and Multicarrier Modulation: A Brief History - Prof. David Falconer, Carleton University
9:55	A Review of OFDMA and SC-FDMA and Some Recent Results - Prof. Hikmet Sari, L'École Supérieure d'Électricité (SUPÉLEC)
10:20	Single-carrier Packet Access In A Frequency-Selective Channel - Prof. Fumiyuki Adachi, Tohoku University
10:45	Break & poster sessions
11:10	Frequency Domain Turbo Equalization for Single Carrier Signaling, and its Information Theoretic Considerations - Prof. Tadashi Matsumoto, University of Oulu & Japan Advanced Institute Science and Technology
11:35	Interleaved Frequency-Division Multiple-Access and Its Relations to SC-FDMA - Dr. Michael Schnell, German Aerospace Center / Institute of Communications and Navigation
12:00	Block-Interleaved Frequency Division Multiple Access (B-IFDMA) and its Application to Future Mobile Radio Systems - Prof. Anja Klein, Technische Universität Darmstadt
12:25	Lunch
13:30	Channel Dependent Scheduling in Single Carrier FDMA - Prof. David J. Goodman, Polytechnic Institute of NYU
13:55	Requirements and Radio Access Techniques for LTE-Advanced - Prof. Mamoru Sawahashi, Musashi Institue of Technology & NTT DoCoMo
14:20	MIMO and Transmit Diversity for SC-FDMA - Donald Grieco, InterDigital Communications
14:45	Break
15:10	Optimal Transmitter and Receiver Design for Single-Carrier Frequency-Division Multiple Access - Dr. Volker Jungnickel, Fraunhofer Institute for Telecommunications / Heinrich-Hertz-Institut
15:35	SC-FDM for Single User MIMO LTE-A Uplink - Gilberto Berardinelli, Aalborg University
16:00	Comparison of Receivers for SC-FDMA Transmission over Frequency-Selective MIMO Channels - Uyen Ly Dang, University of Erlangen-Nuremberg
16:25 – 17:30	Panel discussion and audience Q&A

Oral Presentations

Single and Multicarrier Modulation: A Brief History

Presenter: Professor David Falconer, Carleton University

Abstract: This talk lightheartedly surveys important milestones in the evolution of single carrier (or serial) modulation and multicarrier modulation. During the past 170 years these two transmission modes for digital communications have had their high and low points, and have not always had a harmonious relationship. However in the present frequency domain processing era, they have been united in a marriage of convenience which we hope may endure.

Bio: David Falconer received the B.A. Sc. degree in Engineering Physics from the University of Toronto and the S.M. and Ph.D. degrees in Electrical Engineering from M.I.T. After a year as a postdoctoral fellow at the Royal Institute of Technology, Stockholm, Sweden he was with Bell Laboratories from 1967 to 1980. During 1976-77 he was a visiting professor at Linköping University, Linköping, Sweden. Since 1980 he has been with Carleton University, Ottawa, Canada, where he is now Professor Emeritus and Distinguished Research Professor in the Department of Systems and Computer Engineering.

His current research interests center around beyond-third-generation broadband wireless communications systems. He was Director of Carleton's Broadband Communications and Wireless Systems (BCWS) Centre from 2000 to 2004. He was the Chair of Working Group 4 (New Radio Interfaces, Relay-Based Systems and Smart Antennas) of the Wireless World Research Forum (WWRF) in 2004 and 2005. He received the 2008 Canadian award for Telecommunications Research, a 2008 IEEE Technical Committee for Wireless Communications Recognition Award, and will receive the 2009 Fessenden Award (Telecommunications) from IEEE Canada. He is an IEEE Life Fellow.

A Review of OFDMA and SC-FDMA and Some Recent Results

Presenter: Professor Hikmet Sari, L'École Supérieure d'Électricité (SUPÉLEC)

Abstract: This talk starts with a brief historical review of orthogonal frequency-domain multiple access (OFDMA) and single-carrier transmission with frequency-domain equalization (SC-FDE), both of which originated from the present authors publications in the 1993 – 1996 time period. Next, we describe the general principle of single-carrier frequency-division multiple access (SC-FDMA), which attempts to combine the respective advantages of the two techniques. The latter technique has been adopted by the 3GPP for the uplink of the Long Term Evolution (LTE) standard, while OFDMA is used on downlink of LTE and on both the downlink and uplink of the IEEE 802.16e specifications, on which mobile WiMAX systems are based. In the second part of

the talk, we give the main results of a recent study which compares the performance of OFDMA and SC-FDMA in a cellular environment.

Bio: Hikmet Sari is Professor and Head of the Telecommunications Department at SUPELEC, which is one of the leading graduate schools in France in the field of electrical engineering. Since December 2004, he has also been Chief Scientist of SEQUANS Communications, a Paris-based start-up, which has become one of the top technology companies developing WiMAX chips. Previously, he held scientific and key management positions at Philips, SAT (SAGEM Group), Alcatel, Pacific Broadband Communication and Juniper Networks.

Prof. Sari has published over 180 journal and conference papers, holds over 25 patents, and has given numerous invited talks in Europe, North America, Asia-Pacific, and Latin America. He served on the Awards Committee of the IEEE Communications Society from 2005 to 2007 and on the Fellow Evaluation Committee of this society from 2002 to 2007. He was elevated to the grade of IEEE Fellow in 1995. He received the André Blondel Medal from the SEE (France) in 1995 and the Edwin H. Armstrong Award from the IEEE Communications Society in 2003. He has served as Editor or Guest Editor for several international journals including the IEEE Transactions on Communications, IEEE Journal on Selected Areas in Communications (JSAC), IEEE Communications Letters, European Transactions on Telecommunications and Related Technologies (ETT), and EURASIP Journal on Wireless Communications and Networking. He was Chair of the Communication Theory Symposium of ICC 2002 (April 2002, New York), Technical Program Chair of ICC 2004, (June 2004, Paris) and Vice General Chair of ICC 2006 (June 2006, Istanbul). He is also General Chair of the forthcoming PIMRC 2010.

Single-Carrier Packet Access in a Frequency-Selective Channel

Presenter: Professor Fumiyuki Adachi, Tohoku University

Abstract: Broadband wireless packet access will be a core technology of the next generation mobile communication systems. Turbo coded hybrid ARQ (HARQ) is known as one of the promising error control techniques. Although the broadband channel is very hostile, incorporation of frequency-domain equalization (FDE) into packet access can take advantage of the channel selectivity and significantly improves the throughput performance. However, the cyclic prefix insertion reduces the throughput to some extent. An overlap FDE that requires no CP insertion is attractive. In this talk, packet access using overlap FDE will be presented. In addition to this, single-carrier multiple access techniques using FDE, such as a block spread multiple access and a delay-time domain multiple access, will also be presented.

Bio: Fumiyuki Adachi received the B.S. and Dr. Eng. degrees in electrical engineering from Tohoku University, Sendai, Japan, in 1973 and 1984, respectively. In April 1973, he joined the Electrical Communications Laboratories of Nippon Telegraph & Telephone Corporation (now NTT). From July 1992 to December 1999, he was with NTT Mobile Communications Network,

Inc. (now NTT DoCoMo, Inc.), where he led a research group on wideband/broadband CDMA wireless access for IMT-2000 and beyond. Since January 2000, he has been with Tohoku University, Sendai, Japan, where he is a Professor of Electrical and Communication Engineering at the Graduate School of Engineering. He is an IEEE Fellow and also an IEICE Fellow. He was a recipient of IEEE VTS Avant Garde award 2000, IEICE Achievement Award 2002, Thomson Scientific Research Front Award 2004, and Ericsson Telecommunications Award 2008.

Frequency Domain Turbo Equalization for Single Carrier Signaling, and its Information Theoretic Considerations

Presenter: Professor Tadashi Matsumoto, University of Oulu/Japan Advanced Institute Science and Technology

Abstract: The goal of this talk is to provide the participants with understanding of "turbo equalization", from its fundamentals to information theoretic issues and applications. Technological fundamentals of turbo equalization for broadband single carrier signaling, exemplifying the turbo principle, are provided in this talk with an intensified focus on the technique, frequency domain soft cancellation and minimum mean squared error filtering (FD SC-MMSE) equalization, as a practical and flexible platform. FD SC-MMSE can reduce the computational complexity to the same level as that required by OFDM signaling. FD SC-MMSE is then applied to the multi-user multiple input multiple output (MU-MIMO) cases as a reasonable extension of the technique. The talk will then change the focus to more information theoretic issues, covering convergence property analysis of turbo equalization using the extrinsic information transfer (EXIT) chart as a tool for evaluating the efficiency of mutual information exchange. Asymptotic and convergence properties of the FD SC-MMSE turbo equalization are analyzed. Adaptive coded transmission concept based on EXIT analysis is also provided, of which aim is to achieve the best matching between code and equalizer. Finally, the latest results of our research work, (1) repetition coded Bit Interleaved Coded Modulation with Iterative Detection (BICM-ID) with extended mapping and irregular degree allocation, and (2) Probabilistic Data Association based convergence analysis of equalization systems having internal and global turbo loops are briefly introduced.

Bio: Tad MATSUMOTO received his M.S., and Ph.D. degrees from Keio University, Yokohama, Japan, in 1978, 1980, and 1991, respectively, all in electrical engineering. He joined Nippon Telegraph and Telephone Corporation (NTT) in April 1980. Since he engaged in NTT, he was involved in a lot of research and development projects, all for mobile wireless communications systems. In July 1992, he transferred to NTT DoCoMo, where he researched Code-Division Multiple-Access techniques for Mobile Communication Systems. In April 1994, he transferred to NTT America, where he served as a Senior Technical Advisor of a joint project between NTT and NEXTEL Communications. In March 1996, he returned to NTT DoCoMo, where he served as

a Head of the Radio Signal Processing Laboratory until August of 2001; He worked on adaptive signal processing, multiple-input multiple-output turbo signal detection, interference cancellation, and space-time coding techniques for broadband mobile communications. In March 2002, he moved to University of Oulu, Finland, where he served as a Professor at Centre for Wireless Communications. In 2006, he served as a Visiting Professor at Ilmenau University of Technology, Ilmenau, Germany, funded by the German MERCATOR Visiting Professorship Program. Since April 2007, he has been serving as a Professor at Japan Advanced Institute of Science and Technology (JAIST), Japan, while also keeping the position at University of Oulu.

Prof. Matsumoto has been appointed as a Finnish Distinguished Professor for a period from January 2008 to December 2012, funded by the Finnish National Technology Agency (Tekes) and Finnish Academy, under which he preserves the rights to participate in and apply to European and Finnish national projects. Prof. Matsumoto is a recipient of IEEE VTS Outstanding Service Award (2001), Nokia Foundation Visiting Fellow Scholarship Award (2002), IEEE Japan Council Award for Distinguished Service to the Society (2006), IEEE Vehicular Technology Society James R. Evans Avant Garde Award (2006), and Thuringen State Research Award for Advanced Applied Science (2006), and 2007 Best Paper Award of Institute of Electrical, Communication, and Information Engineers of Japan.

Interleaved Frequency-Division Multiple-Access and Its Relations to SC-FDMA

Presenter: Dr. Michael Schnell, German Aerospace Center / Institute of Communications and Navigation

Abstract: In this contribution, an overview of Interleaved Frequency-Division Multiple-Access (IFDMA) is provided together with a brief “historical” review on early achievements and developments. Moreover, the relation between IFDMA and both Orthogonal Frequency-Division Multiple-Access Code-Division Multiplexing (OFDMA-CDM) and Single-Carrier Frequency-Division Multiple-Access (SC-FDMA) is described and differences as well as communalities are highlighted. In addition to this general overview of IFDMA, some research results with respect to the peak-to-average power ratio (PAPR) performance of IFDMA are presented. Both IFDMA based on Quadrature Phase-Shift Keying (QPSK) modulation with standard raised-cosine pulse-shaping and IFDMA utilizing spectrum-efficient modulation schemes, like Minimum-Shift Keying (MSK) and Gaussian-Offset QPSK (GO-QPSK), are investigated and compared to OFDMA-CDM. As a result – see figure below – IFDMA with pulse-shaping or spectrum-efficient modulation outperforms OFDMA-CDM significantly, where IFDMA with MSK or GO-QPSK are even better than IFDMA with standard pulse-shaping.

Bio: He received his Dipl.-Ing. (M.Sc.) degree in Electrical Engineering from the University of Erlangen-Nuremberg, Germany, in 1987. In 1997, he received his Dr.-Ing. (Ph.D.) degree from University of Essen, Germany, for his work in the field of spread-spectrum multiple-access

communications. Since 1990 he is scientific researcher at the Institute of Communications and Navigation of the German Aerospace Center (DLR) in Oberpfaffenhofen near Munich where he is currently group leader and project manager of the Aeronautical Communications Group. He has been involved in several national and international projects in the area terrestrial and aeronautical communications.

Dr. Schnell is Lecturer for multi-carrier communications at the University of Karlsruhe, Germany, and acts as selected Advisor for the German Air-Traffic Control Provider DFS within the Aeronautical Communications Panel of the International Civil Aviation Organization. He is Senior Member IEEE, member of the Organizing Committee of the Information Theory Society of the IEEE Germany Chapter, and member of VDE/ITG.

Block-Interleaved Frequency Division Multiple Access (B-IFDMA) and its Application to Future Mobile Radio Systems

Presenter: Professor Anja Klein, Technische Universität Darmstadt

Abstract: For Discrete Fourier Transform (DFT) pre-coded Orthogonal Frequency Division Multiple Access (OFDMA), there exist different possibilities of allocating subcarriers to a certain user. Interleaved subcarrier allocation leads to the well-known Interleaved Frequency Division Multiple Access (IFDMA). It provides high frequency diversity due to the spreading of the subcarriers over the total available bandwidth, and, compared to other DFT pre-coded OFDMA schemes, IFDMA exhibits the lowest Peak-to-Average Power Ratio. However, IFDMA is sensitive to carrier frequency offsets. Moreover, in terms of channel estimation, IFDMA requires a higher pilot symbol overhead than Localized Frequency Division Multiple Access (LFDMA) since, in general, for IFDMA interpolation between different subcarriers in frequency domain is not possible. In this talk, Block Interleaved Frequency Division Multiple Access (B-IFDMA) is considered, where the data of a specific user is transmitted on blocks of adjacent subcarriers that are equidistantly distributed over the available bandwidth. Thus, BIFDMA is a generalization of IFDMA, where a block is built by a single subcarrier. Due to the block-wise subcarrier allocation, B-IFDMA exhibits higher robustness against carrier frequency offsets than IFDMA and, at the same time, maintains the advantage of high frequency diversity. In terms of pilot assisted channel estimation, interpolation in frequency domain is applicable for B-IFDMA within each block of adjacent subcarriers. Thus, B-IFDMA benefits from a lower pilot symbol overhead compared to IFDMA if the distance between neighboring blocks is larger than the coherence bandwidth. In the talk, the properties of B-IFDMA will be discussed and its advantages compared to other transmission schemes will be highlighted. Further on, the aspect of channel estimation will be addressed and the approach of semi-blind channel estimation will be investigated.

Bio: Anja Klein received the diploma and Dr.-Ing. (Ph.D.) degrees in electrical engineering from University of Kaiserslautern, Germany, in 1991 and 1996, respectively. From 1991 to 1996, she was a member of the staff of the Research Group for RF Communications at University of Kaiserslautern. In 1996, she joined Siemens AG, Mobile Networks Division, Munich and Berlin. She was active in the standardization of third generation mobile radio in ETSI and in 3GPP. She was vice president, heading a development department and a systems engineering department. In May 2004, she joined Darmstadt University of Technology, Germany, as full professor, heading the Communications Engineering Lab. Her main research interests are in mobile radio, including multiple access and transmission techniques like single and multi carrier schemes and multi antenna systems on the one hand, and network aspects like resource management, network planning and dimensioning, cross-layer design and relaying and multi-hop on the other hand.

Dr. Klein has published over 140-refereed papers and has contributed to five books. She is inventor and co-inventor of more than 45 patents in the field of mobile radio. In 1999, she was inventor of the year of Siemens AG. Dr. Klein is a member of IEEE and of Verband Deutscher Elektrotechniker - Informationstechnische Gesellschaft (VDE-ITG).

Channel Dependent Scheduling in Single Carrier FDMA

Presenter: Professor David J. Goodman, Polytechnic Institute of NYU

Abstract: A base station that receives single-carrier FDMA signals from several mobile terminals assigns subcarriers to each terminal based on measurements of the channel conditions at all of the terminals. Channel dependent scheduling can combat the effects of fading by means of multi-user diversity or frequency diversity. Multi-user diversity can best be achieved with localized scheduling algorithms, while frequency diversity is associated with distributed scheduling. Simulations show that localized scheduling is potentially more effective. However, it requires accurate channel state information. This talk presents the results of simulation studies that show the effects of channel state information on throughput obtained with localized scheduling and distributed scheduling.

Bio: David Goodman is Professor Emeritus at Polytechnic Institute of New York University. In 2008, he retired from his position as Professor of Electrical and Computer Engineering and Director of WICAT the Wireless Internet Center for Advanced Technology. Prior to joining Polytechnic in 1999 he was at Rutgers University where he was founding director of WINLAB. Until 1988 he was head of the Radio Research Department at Bell Labs. He is a Fellow of the IEEE and a member of the National Academy of Engineering.

Requirements and Radio Access Techniques for LTE-Advanced

Presenter: Professor Mamoru Sawahashi, Musashi Institue of Technology & NTT DoCoMo

Abstract: The work item (WI) specification on the Universal Mobile Telecommunications System (UMTS) Long-Term Evolution (LTE) called the Evolved UMTS Terrestrial Radio Access (UTRA) and UMTS Terrestrial Radio Access Network (UTRAN) was finalized as Release 8 (Rel. 8 LTE) in the 3rd Generation Partnership Project (3GPP). Rel. 8 LTE will provide full IP-based functionalities through efficient packet-based radio access and radio access networks with low latency and low cost. The frequency spectrum for International Mobile Telecommunications (IMT)-Advanced was decided at the World Radiocommunication Conference 2007 (WRC-07) held in November 2007. According to the decision on the available frequency spectrum outline however, standardization of a radio interface started in the 3GPP last year. The requirements for LTE-Advanced were agreed upon and the radio interface techniques are currently under discussion aiming at a proposal to the International Telecommunication Union-Radio (ITU-R) this fall. In the presentation, after the technical background is discussed, the requirements of LTE-Advanced to achieve continuous enhancements from Rel. 8 LTE will be presented. One of the most important requirements for LTE-Advanced is to support Rel. 8 LTE including its enhancement in the same frequency spectrum. Hence, OFDMA and N-times DFT-Spread OFDM were adopted as multi-access schemes in the downlink and uplink, respectively, to achieve full backward compatibility with Rel. 8 LTE. These multi-access schemes will be presented and the technical issues that remain will be addressed. Moreover, the key radio access technologies will be described such as fast inter-cell radio resource management, which take advantage of remote radio equipment (RRE) aiming at inter-cell orthogonality, multi-antenna transmissions with more antennas, and coverage enhancing techniques to achieve a high level of the average and cell-edge spectrum efficiency.

Bio: Mamoru Sawahashi received his B.S. and M.S. degrees from Tokyo University in 1983 and 1985, respectively, and received his Dr. Eng. Degree from the Nara Institute of Technology in 1998. In 1985, he joined the NTT Electrical Communications Laboratories, and in 1992 he transferred to the NTT Mobile Communications Network, Inc. (now NTT DOCOMO, INC.). In NTT, he was engaged in the research of modulation/demodulation techniques for mobile radio. He was also engaged in the research and development of radio access technologies for W-CDMA mobile communications and broadband packet radio access technologies for the 3G long-term evolution (LTE) and for LTE-Advanced in NTT DOCOMO. From April 2006, he assumed the position of Professor of the Department of Electronics and Communication Engineering, Musashi Institute of Technology. From 2006, he has been a part-time director of the Radio Access Development Department of NTT DOCOMO. In 2005 and 2006, he served as a guest editor of the IEEE JSAC on Intelligent Services and Applications in Next-generation Networks, 4G Wireless Systems, and Advances in Multicarrier CDMA.

MIMO and Transmit Diversity for SC-FDMA

Presenter: Donald Grieco, InterDigital Communications

Abstract: A general description of MIMO/transmit diversity for SC-FDMA will be presented. Specific transmit diversity and MIMO techniques will be described. Various MIMO receivers will be discussed. MIMO simulated performance comparisons with SIMO, transmit diversity and spatial multiplexing will be presented. Lastly, MIMO performance of SC-FDMA will be compared with that of OFDMA.

Bio: Donald M. Grieco received his BE(Electrical Engineering) from Manhattan College and his MS(Systems Science) from the Polytechnic Institute of Brooklyn, where he became a PhD Candidate in Systems Engineering. He has extensive experience in wireless communications for both military and commercial applications, having worked at Hazeltine (now part of BAE Systems), Grumman and Omnipoint (now part of T-Mobile USA). He is currently a Principal Engineer at InterDigital Communications where he contributed to the development of 3GPP WCDMA modem designs and more recently the standardization of 3GPP LTE. He has authored or co-authored over 20 technical papers in journals or conference proceedings. He also has over 30 issued US patents. Additionally, he has taught graduate EE courses at Polytechnic University and Stevens Institute. In 1988 he received the Charles Hirsh Award from Long Island IEEE for "contributions to C3I research."

Optimal Transmitter and Receiver Design for Single-Carrier Frequency-Division Multiple Access

Presenter: Dr. Volker Jungnickel, Fraunhofer Institute for Telecommunications / Heinrich-Hertz-Institut

Abstract: This contribution summarizes recent work on the optimal transmitter and receiver design for single-carrier frequency-division multiple access (SC-FDMA). Optimized raised cosine filting can reduce the peak-to-average power ratio at the transmitter if the SNR is low. This may be of particular interest to boost the power of cell-edge users in the uplink. Next we show that the complex but optimal multiuser RAKE receiver for SC-FDMA is mathematically equivalent to the commonly used frequency-domain equalization and subsequent IDFT. Hence the full multipath diversity can be realized with much less effort. Finally we compare the performance of SC-FDMA and OFDMA.

Bio: Volker Jungnickel received the Dipl.-Phys. (M.S.) and Dr. rer. nat. (Ph.D.) degrees in experimental physics, both from Humboldt University in Berlin, Germany, in 1992 and 1995, respectively. He has worked on photoluminescence of semiconductor quantum dots and minimal-invasive laser-surgery before joining the Fraunhofer Institute for Telecommunications (Heinrich-Hertz-Institut) in 1997. After completing a 155 Mbit/s wireless indoor

communications link based on infrared his research is focussed on broadband multiple-input multiple-output (MIMO) systems. He has completed a 1 Gbit/s MIMO-OFDM radio link in real time. He transferred the knowledge into the first experimental link for the 3GPP Long Term Evolution which has been used for initial field trials. His current research is concerned with interference management in next generation cellular systems. Volker is a lecturer at the Technical University in Berlin and a member of the IEEE.

SC-FDM for Single User MIMO LTE-A Uplink

Presenter: Gilberto Berardinelli, Aalborg University

Abstract: Single Carrier Frequency Division Multiplexing (SC-FDM) has been selected by the 3rd Generation Partnership Project (3GPP) for the uplink of the Long Term Evolution (LTE) standard. This modulation scheme, which is still a strong candidate for the upcoming LTE-Advanced (LTE-A) systems, is a Discrete Fourier Transform (DFT) spread version of Orthogonal Frequency Division Multiplexing (OFDM) and exploits similar benefits in terms of multipath mitigation and flexibility in the resources allocation, at the same time providing low Peak-to-Average Power Ratio (PAPR) of the transmit signals. While in LTE only single transmit antenna schemes have been standardized for the uplink, in LTE-A Multiple Input Multiple Output (MIMO) antenna techniques are expected to be deployed to meet the ambitious target data rate of 500 Mbit/s. In this talk, the suitability of SC-FDM for Single User MIMO is discussed and its performance is compared with OFDM. It is shown that OFDM tends to outperform SC-FDM in terms of spectral efficiency when linear receivers are used because of the “noise enhancement” drawback of the latter. This gap can be reduced by adding diversity branches. Furthermore, a more complex receiver based on iterative detection (turbo receiver) is shown to provide higher relative gain for SC-FDM than for OFDM, resulting in similar link level performance for both the modulation schemes. The effect of the closed loop precoded transmission on the PAPR of SC-FDM signals is also discussed.

Bio: Gilberto Berardinelli (gb@es.aau.dk) received his first and second level laurea degrees in telecommunication engineering, cum laude, from University of L’Aquila, Italy, in 2003 and 2005, respectively. He also received a second level master in techniques and economics of telecommunications in 2006 from the University of Padova, Italy. In 2006 he worked with the Radio Frequency Engineering Department in Vodafone NV, Padova, where he studied the issues related to the coverage of HSDPA services, and also radio propagation in urban and suburban environments. Since 2007 he has been employed as a research assistant in the Radio Access Technology Section of Aalborg University, Denmark, and successively appointed as a Ph.D. student in the same section. His research interests are mostly focused on physical layer design for 4G systems, thus including multiple access schemes, multi-antenna systems and iterative turbo receivers. He collaborates with Nokia-Siemens Networks in the development of solutions for upcoming LTE-A systems.

Comparison of Receivers for SC-FDMA Transmission over Frequency-Selective MIMO Channels

Presenter: Uyen Ly Dang, University of Erlangen-Nuremberg

Abstract: In this work the performance of different receivers for single-carrier frequency division multiple access (SC-FDMA) transmission over frequency-selective fading channels is investigated. The receiver design is done for a single-user multiple-input multiple-output (MIMO) system. Linear equalization in frequency domain according to the minimum mean-squared error (MMSE) criterion is compared to joint trellis-based equalization using reduced state sequence estimation (RSSE). Finally, successive interference cancelation in time domain is considered, where the signals of the transmit antennas are equalized in subsequent stages.

Bio: Uyen Ly Dang has studied electrical engineering with specialization in information technologies at University of Erlangen-Nuremberg, Germany. She received her Diploma degree in 2007. Since 2008 she is working at the Chair of Mobile Communications at University of Erlangen-Nuremberg towards a PhD degree. Her current work focuses on the physical layer of Long Term Evolution (LTE).

Poster Presentations

Performance Analysis of Precoded LTE-Advanced Uplink Considering Non-linear Transmit Amplifier

Authors: Young Ju Kim, Xun Li, Noe Yoon Park, and Kwan Seob Lee (Chungbuk National University)

Abstract: In this paper, BER performance with maximum ratio transmission (MRT) and equal gain transmission (EGT) for LTE-Advanced uplink is investigated, and peak-to-average power ratio (PAPR) is also analyzed. Since EGT precoding scheme does not change the amplitudes of transmitted signal, it maintains a good PAPR performance with SC-FDMA technique, and performs very well even in non-linear amplifier channel model. It can be a good candidate of uplink precoding scheme for LTE-Advanced. Link level computer simulation comparisons with various precoding schemes illustrate the CCDFs of PAPR and BER performance.

Impact of Pulse Shapings on Envelope Fluctuations of SC-FDMA Signals

Authors: Xuegui Song and Julian Cheng (UBC Okanagan)

Abstract: Single-carrier frequency division multiple access (SC-FDMA) has been proposed in the third Generation Partnership Project (3GPP) for the Long Term Evolution (LTE) uplink communication. Because SC-FDMA signal has low envelope fluctuation. Comparison of envelope fluctuations between orthogonal frequency division multiple access (OFDMA) signal and SC-FDMA signal has been studied in [1] [2]. It is reported that SC-FDMA signal has lower envelope fluctuation than OFDMA signal, and pulse shaping and subcarrier mappings can have impact on the envelope fluctuation. However only systems with raised cosine (RC) pulse shaping has been considered. In this work, we propose to study the impact of different bandlimited pulse shapings on SC-FDMA signals.

Channel Estimation Approaches for B-IFDMA – Interpolation Filters versus Decision Directed Estimation

Authors: Anja Sohl and Anja Klein (Technische Universität Darmstadt)

Abstract: In terms of Pilot Assisted Channel Estimation (PACE), interpolation in frequency domain is applicable for Block-IFDMA (B-IFDMA) within each block of adjacent subcarriers. Thus, B-IFDMA benefits from a lower pilot symbol overhead compared to IFDMA if the distance between neighboring blocks is larger than the coherence bandwidth. The application of interpolation filters in frequency domain, which is a favorable technique to estimate the channel for the non-pilot carrying subcarriers, involves the usage of at least two subcarriers within each block of subcarriers in frequency domain for pilot transmission. If there is only one subcarrier per block used for pilot transmission, the estimate of the pilot carrying subcarrier is repeated for equalization of the remaining subcarriers in the block. In this case, the reduction of the pilot symbol overhead goes at the expense of the channel estimation performance. The poster will give an overview of channel estimation for B-IFDMA and will contribute to the aspect of different pilot insertion methods, as well as preferable pilot arrangements. Further on, different channel estimation approaches for B-IFDMA, such as interpolation with a Wiener interpolation filter, repetition or decision directed channel estimation, and their various combinations in time and frequency domain will be compared by numerical results.

Channel estimation for the uplink 2x2 MIMO SC-FDMA systems

Authors: Kun-Ju Tsai and I-Tai Lu (Polytechnic Institute of NYU)

Abstract: A model-based approach is developed for a 3GPP E-UTRA LTE uplink 2x2 MIMO SC-FDMA system to estimate the channel impulse responses from all transmitters to all receivers accurately within one pilot block. The performance of this modal based channel estimation

approach is evaluated using the Normalized Mean Square Error (NMSE) computation and the performance of data detection is evaluated using the Block Error Rate (BLER) measurements. From the NMSE result, it is evident that the performances of the TU and SCME-C channels were almost the same which is mainly due to similar delay spreads. On the other hand the SCME-D channel has much lower NMSE result as compared to the TU and the SCME-C channels because of the much lower delay spread. We conclude that channel estimation error of the proposed approach is independent of spatial correlation among MIMO channel impulse responses. But the error is proportional to the delay spreads of channel impulse responses. The longer the delay spreads, the larger the channel estimation error.

Adaptive Scheduling for Uplink SC-FDMA System with Imperfect Channel State Information

Authors: Kyungjin Oh and David J. Goodman (Polytechnic Institute of NYU)

Abstract: To achieve a maximized utility of radio resource in using SC-FDMA, an adaptive scheduling as well as an adaptive modulation are necessary. Although the adaptive scheduling needs a perfect CSI (channel state information), it is not practically possible due to several reasons such as limited feedback, processing delay, mobility of user, etc. In this presentation, we investigate the performance degradation of SC-FDMA adaptive scheduling for each resource allocation method (localized and interleaved FDMA) in the presence of imperfect CSI and we also try to find out any possible overcoming method to this inferiority.