

THE 8th INTERNATIONAL CONFERENCE on ADVANCED COMMUNICATION TECHNOLOGY

Toward the Era of Ubiquitous Networks and Societies



Phoenix Park, Korea
Feb. 20–22, 2006

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MESSAGE

Message from the ICACt2006 General and Organizing Chairs

On behalf of the ICACt2006 Organization and Operation Committee, I extend our warm welcome to the professionals in the field of communications from all over the world present at this grand meeting, namely International Conference on Advanced Communication Technology 2006. The ICACt2006, the 8th of the series conference, is a series of international academic event in the communications field, which all the experts from home and abroad gather to present their work, and share new ideas and visions for achieving the future telecommunication age. I hope that you will enjoy both the excellent technical content and recreational parts of the meeting.



The communication network is in a transition toward the era of ubiquitous networks and services received increasing attention over the last two or three years. No one can deny that technology has already permeated diverse aspects of human life. Mobile phones and the Internet -- the biggest success stories our industry has ever seen -- are only the beginning. The Ubiquitous Networks and Services will make it possible to connect anytime, anywhere, by anything and anyone. In a ubiquitous network, everyone and everything can be connected, and new innovations that will completely change the current dimension of IT technology are expected. ICACt2006 will provide the present and future of the ubiquitous networks and services. It will also give the basic characteristics, applications, issues and standardization of the ubiquitous networks and services.

In closing, I would like to express my sincere appreciation for the committee members and the referees for their contributions who have been helping us to prepare the event. I also sincerely thank all the authors for the papers on their precious technical achievements. I have no doubt of successful ICACt2006, and you will enjoy both the high technical talks of the sessions and the beautiful landscapes of Phoenix Park.

Have a pleasant stay in Phoenix Park.

IEEE ICACt2006
Professor Minho Kang, General Chairman
Dr. Thomas Byeong-Nam Yoon, Organizing Chairman



MESSAGE

Message from the Technical Program Committee Chair

I would like to welcome to ICACt2006! It is a great pleasure to host this 8th ICACt2006 in Korea which is one of the countries recently drawing much attention in the world arena of high speed Internet.

ICACt is an IEEE-sponsored annual conference providing an open forum for researchers, engineers, policy makers, network planners, and service providers in telecommunications. Extensive exchange of information will be provided on newly emerging systems, standards, regulations, services, and variety of applications in the area of telecommunications.



Korea has richly benefited from deploying the high-speed Internet and Cellular networks providing various IT services all over the country. Approximately 80%, i.e. 13 millions, of Korean households use the high-speed Internet services, and 79%, i.e. 38 millions, of Korean people use the CDMA mobile phones now.

In Korea, with a goal to develop a new virtuous cycle, the Ministry of Information and Communication drew up the IT839 Strategy, which includes 8 Services, 3 Infrastructures, and 9 New Growth Engines.

8 Services are WiBro, DMB, Home Network, Telematics, RFID, W-CDMA, Terrestrial DTV, and VoIP. 3 Infrastructures are Broadband convergence Network(BcN), Ubiquitous Sensor Network(USN), and IPv6. 9 New Growth Engines are Next-Generation Mobile Communications Devices, Digital TV/Broadcasting Devices, Home Network Devices, IT System-on-Chip(SoC), Next-Generation PC, Embedded Software, Digital Contents(DC) and Software Solutions, Telematics Devices, and Intelligent Service Robot.

In this way, 8 new services will prompt investment into 3 essential networks. And these networks will be the highways for 9 new sectors to grow fast, creating synergetic effects.

The theme of ICACt2006 is "Toward the Era of Ubiquitous Networks and Societies." ICACt 2006 consists of 77 technical sessions including 2 poster sessions and an invited session with two remarkable world experts. The TPC carefully selected a limited number of 442 papers from 27 countries to be presented in the technical sessions. We hope these technical sessions will help you obtain better insights into the latest trends and directions for the increasingly competitive future communications and Internet markets. I am sure there will be an abundance of intelligent debate and information exchange, a look at what is new in the field and technology, and lots there.

Thank you everyone who has contributed to the technical program - the authors, the reviewers, and the technical program committee members for their terrific work in collecting and editing the papers. On behalf of the Technical Program Committee, I wish you a productive and enjoyable conference.

Dr. Hyeong-Ho Lee
ICACt2006 Technical Program Committee Chairman



OBJECTIVES

ICACT will provide an open forum for researchers, engineers, policy makers, network planners, and service providers in telecommunications. Extensive change of information will be provided on newly emerging systems, standards, services and variety of applications in the area of telecommunications.



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SESSION OVERVIEW

February 19 (Sunday)								
15:00 ~ 18:00	Registration (2 nd Floor, Phoenix Park Hotel)							
Day 1 : February 20 (Monday)								
08:00 ~ 18:00	Registration (2 nd Floor, Phoenix Park Hotel)							
Room	Emerald	Ruby I	Ruby II	Diamond I	Topaz I	Topaz II	Topaz III	Diamond II
09:00 ~ 10:20	Session 1A	Session 1B	Session 1C	Session 1D	Session 1E	Session 1F	Session 1G	
	CDMA & Wireless Communications (I)	Mobile Communications (I)	Multimedia and Internet Systems and Services (I)	Next Generation Network Technology (I)	Information Security Technology (I)	RFID & USN Technologies (I)	System and Software Engineering (I)	
10:20 ~ 10:40	Coffee Break							
10:40 ~ 12:00	Session 2A	Session 2B	Session 2C	Session 2D	Session 2E	Session 2F	Session 2G	
	CDMA & Wireless Communications (II)	Mobile Communications (II)	Multimedia and Internet Systems and Services (II)	Next Generation Network Technology(II)	Information Security Technology (II)	RFID & USN Technologies (II)	System and Software Engineering (II)	
12:00 ~ 13:20	Lunch							
13:20 ~ 14:40	Session 3A	Session 3B	Session 3C	Session 3D	Session 3E	Session 3F	Session 3G	
	CDMA & Wireless Communications (III)	Mobile Communications (III)	Multimedia and Internet Systems and Services (III)	Next Generation Network Technology (III)	Information Security Technology (III)	RFID & USN Technologies (III)	System and Software Engineering (III)	
14:40 ~ 15:00	Coffee Break							
15:00 ~ 16:20	Session 4A	Session 4B	Session 4C	Session 4D	Session 4E	Session 4F	Session 4G	Session 4H
	CDMA & Wireless Communications (IV)	Mobile Communications (IV)	Multimedia and Internet Systems and Services (IV)	Next Generation Network Technology (IV)	Information Security Technology (IV)	RFID & USN Technologies (IV)	System and Software Engineering (IV)	Poster Session (I)
16:20 ~ 16:40	Coffee Break							
16:40 ~ 18:00	Session 5A	Session 5B	Session 5C	Session 5D	Session 5E	Session 5F	Session 5G	
	CDMA & Wireless Communications (V)	Mobile Communications (V)	Multimedia and Internet Systems and Services (V)	Next Generation Network Technology (V)	Information Security Technology (V)	RFID & USN Technologies (V)	Optical Networking Technology (I)	



SESSION OVERVIEW

Day 2 : February 21 (Tuesday)								
08:00 ~ 18:00	Registration (2 nd Floor, Phoenix Park Hotel)							
Room	Emerald	Ruby I	Ruby II	Diamond I	Topaz I	Topaz II	Topaz III	Diamond II
09:00 ~ 10:20	Session 6A	Session 6B	Session 6C	Session 6D	Session 6E	Session 6F	Session 6G	
	CDMA & Wireless Communications (VI)	Mobile Communications (VI)	Multimedia and Internet Systems and Services(VI)	Broadband Satellite & HAPS	Information Security Technology(VI)	IT Service Technology (I)	Optical Networking Technology (II)	
10:20 ~ 10:30	Coffee Break							
10:30 ~ 12:00	Invited Session (Phoenix Ballroom)							
12:00 ~ 13:20	Opening Ceremony and Banquet (Phoenix Ballroom)							
13:20 ~ 14:40	Session 7A	Session 7B	Session 7C	Session 7D	Session 7E	Session 7F	Session 7G	
	CDMA & Wireless Communications (VII)	Mobile Communications (VII)	Multimedia and Internet Systems and Services (VII)	Telematics Technology	Information Security Technology(VII)	IT Service Technology (II)	Optical Networking Technology (III)	
14:40 ~ 15:00	Coffee Break							
15:00 ~ 16:20	Session 8A	Session 8B	Session 8C	Session 8D	Session 8E	Session 8F	Session 8G	Session 8H
	CDMA & Wireless Communications (VIII)	Mobile Communications (VIII)	Multimedia and Internet Systems and Services (VIII)	Digital Home Technology (I)	Information Security Technology (VIII)	IT Service Technology (III)	Digital Broadcasting Technology (I)	Poster Session (II)
16:20 ~ 16:40	Coffee Break							
16:40 ~ 18:00	Session 9A	Session 9B	Session 9C	Session 9D	Session 9E	Session 9F	Session 9G	
	CDMA & Wireless Communications (IX)	Mobile Communications (IX)	Multimedia and Internet Systems and Services (IX)	Digital Home Technology (II)	ASP, WAS, P2P, CDN, and XML Technologies	IT Service Technology (IV)	Digital Broadcasting Technology (II)	



SESSION OVERVIEW

Day 3 : February 22 (Wednesday)								
08:00 ~ 12:00	Registration (2 nd Floor, Phoenix Park Hotel)							
Room	Emerald	Ruby I	Ruby II	Diamond I	Topaz I	Topaz II	Topaz III	Diamond II
09:00 ~ 10:20	Session 10A	Session 10B	Session 10C	Session 10D	Session 10E	Session 10F		
	CDMA & Wireless Communications (X)	Mobile Communications (X)	IPv6 Technology (I)	Communication Network Topology & Planning (I)	GRID, Distributed Computing Technologies & Services (I)	Portable Internet and Internet Telephony		
10:20 ~ 10:40	Coffee Break							
10:40 ~ 12:00	Session 11A	Session 11B	Session 11C	Session 11D	Session 11E	Session 11F		
	CDMA & Wireless Communications (XI)	Network Management, Operation and Maintenance	IPv6 Technology (II)	Communication Network Topology & Planning (II)	GRID, Distributed Computing Technologies & Services (II)	E-Commerce and M-Commerce		



TABLE of CONTENTS

Volume I

Session 1A: CDMA & Wireless Communications (I)

<i>1. Reliable Blind Channel Estimation scheme based on Cross-correlated Cyclic Prefix for OFDM System</i>	
Taejoon Kim, Iksoo Eo (ETRI, Korea)	3
<i>2. A Novel Frequency Offset Estimation Scheme Using Coherence Phase Bandwidth and Threshold for OFDM Systems</i>	
Sanghun Kim, Seokho Yoon (Sungkyunkwan University, Korea), Sun Yong Kim (Konkuk University, Korea) ...	6
<i>3. Detection Algorithm Improving Parallel Interference Cancellation for V-BLAST System over Error Propagation</i>	
Wei Zhu, Jiyu Jin, Yongwan Park (Yeungnam University, Korea)	11
<i>4. A New Scheduling Algorithm and Performance with Opportunistic Beamforming</i>	
Ting-rui Pei, Zhen Peng, Jiang-lian Cao, Zhi-qiang Yao (Xiangtan University, China)	16
<i>5. Pilot Embedded scheme for Time-Variant Channel Estimation in OFDM Systems</i>	
Lidong Wang, Dongmin Lim (Gyeongsang National University, Korea)	22

Session 1B: Mobile Communications (I)

<i>1. Network Configuration for Mobility in Mobile IP based System</i>	
Yun-Ji Ban (ETRI, Korea), Jung-Min Joo (KARI, Korea), Wonseok Chae, Chungwan Lee, Kwang-Hyun Shim (ETRI, Korea)	29
<i>2. Data and Query Dissemination in Wireless Sensor Networks</i>	
Karthick Kandaswamy, Jyotsna Patel, M V Ramakrishna (Monash University, Australia)	34
<i>3. A Study of QoS-aware MAC Protocol with Network Adaptation</i>	
Hwi-Jin Ye, Moon Kim (Graduate School of Hankuk Aviation University, Korea), Il-Young Moon (Korea University of Technology & Education, Korea), Sung-Joon Cho (Graduate School of Hankuk Aviation University, Korea)	38
<i>4. A New Mobile Internet Search Engine-Based Advertising Method and Theory</i>	
Xiaoping Wang, Zhehong Tang (China Telecom, China), Hui Luo (Broadcom Corporation, USA)	43

5. Multi - Agent System based Efficient Healthcare Service

Byung-mo Han, Seung-Jae Song, Kyu-Min Lee (Sungkyunkwan University, Korea), Kyung-Soo Jang
(Kyungin Women's College, Korea), Dong-Ryeol Shin (Sungkyunkwan University, Korea) 47

Session 1C: Multimedia and Internet Systems and Services (I)

1. Threshold-based Admission Control Method for Multicast Environment

Seng Kyoun Jo, Dipnarayan Guha, Jun Kyun Choi (ICU, Korea), Seong Gon Choi (CBNU, Korea),
Jae Hum Lee (ETRI, Korea) 55

2. A 4-stage IPR Processing Evolution Model in Computer Communication Standardization

Toshihiko Yamakami (ACCESS, Japan) 60

3. Optimization of Memory Management for H.264/AVC Decoder

Shin-Haeng Ji, Jung-Wook Park, Shin-Dug Kim (Yonsei University, Korea) 65

**4. A New Progressive Image Transmission Scheme Based on Content Feature and Gaussian
Model of 2D Gel Electrophoresis Images**

Tzu-Shin Tsai (Chung Shan Medical University, Taiwan), Tung-Shou Chen (National Taichung Institute of
Technology, Taiwan), Jeanne Chen (Hungkuang University, Taiwan), Shih-Shan Tang (National Taichung
Institute of Technology, Taiwan), Ming-Chih Chou, Shuan-Yow Li (Chung Shan Medical University, Taiwan),
Tian-Shing Wang (National Taichung Institute of Technology, Taiwan) 69

**5. Optimizing System Performance for Uncompressed HD over Gigabit Ethernet:
A Case Study**

Jinyong Jo, Junguk Kong, Okhwan Byeon (KISTI, Korea) 75

Session 1D: Next Generation Network Technology (I)

1. Performance Analysis of 2-1-1 Relaying Protocol in Wireless Sensor Networks

Ho Van Khuong, Hyung-Yun Kong (University of Ulsan, Korea) 81

**2. The Public Packet-Switched Network with Guaranteed QoS Based on DiffServ Domains
Hierarchy**

Yevgeni Koucheryavy (Tampere University of Technology, Finland), Alexey Vasiliev, Sergei Soloviev,
Andrey Koucheryavy (ZNIIS, Russian Federation) 87

3. Resilient Data Delivery in Delay Bounded Overlay Multicast

Dongkyun Kim, Ki-Sung Yu, Byung-Hyeon Park (KISTI, Korea), Sang-Ha Kim (Chungnam National
University, Korea) 91

4. A “Customer Satisfaction” Based Migration Approach toward NGN	
Mohamed Jamoussi, Majed Al Salem (Saudi Telecom Co., Saudi Arabia)	97
5. Universal Ethernet Networks Based on Cycle Reservation Scheduling	
Seong-Soon Joo(ETRI, Korea), Young-Cheol Bang (Korea Polytechnic University, Korea)	102

Session 1E: Information Security Technology (I)

1. Considerations on Security Model of Home Network	
Geon-Woo Kim, Do-Woo Kim, Jun-Ho Lee, Jin-Beon Hwang, Jong-Wook Han (ETRI, Korea)	109
2. On the Study of Service Security Model for Privacy using Global User Management Framework	
Byeong-Cheol Choi, Dong-il Seo (ETRI, Korea)	113
3. Hardware Implementation of Fast Division Algorithm for GF(2^m)	
Min-Sup Kang, Kwang-Ho Lee (Anyang University, Korea)	117
4. Fragment Packet Partial Re-assembly Method for Intrusion Detection	
Bo-Heung Chung, Jae-Deok Lim, Seung-Ho Ryu, Young-Ho Kim, Ki-Young Kim (ETRI, Korea)	120
5. A Revised LKK Proxy Blind Signature Scheme	
Jong-Ho Ryu, Kook-Han Kim, Dong-Il Seo (ETRI, Korea)	123

Session 1F: RFID & USN Technologies (I)

1. Node-link-failure Resilient Routing Architecture for Sensor Grids	
Ali Hammad Akbar, Waleed Mansoor, Shafique Ahmad Chaudhry, Ali Kashif, Ki-Hyung Kim (Ajou University, Korea)	131
2. Context-Aware Services Platform Supporting Mobile Agents For Ubiquitous Home Network	
JungRae Kim, JaeDoo Huh (ETRI, Korea)	136
3. A Cluster Based Query Protocol for Wireless Sensor Networks	
Zhanyang Zhang (City University of New York, USA), Guping Zheng (North China Electric Power University, China)	140
4. The Gateway Implementation of Sensor Network using the ARM Chip	
Dal-Hwan Yoon, Ye Heon Jung, Hak Jong Ryoo, Hyung Mook Kim (Semyung University, Korea), Sung Young Choei (FielTech. Co.Ltd., Korea)	146
5. Performance Test Tool for RFID Middleware : Parameters, Design, Implementation, and Features	
Jongyoung Lee, Naesoo Kim (ETRI, Korea)	149

Session 1G: System and Software Engineering (I)

1. *Eclipse-Based Management System for Process Innovation & Methodology Enhancement*
Yoonjung Choi, Su-Jung Ha, Jin-Sam Kim (ETRI, Korea) 155
2. *A Methodological Framework for Conceptual Modeling of Optical Networks*
Sudip Misra (Cornell University, USA), Subhas Misra (Super Net Solutions, Canada), Isaac Woungang (Ryerson University, Canada) 160
3. *Implementation of Lightweight Graphic Library Builder for Embedded System*
SungHo Ahn, DongMyung Sul, SeungHan Choi, KyungHee Lee (ETRI, Korea) 166
4. *Performance Anomalies of Advanced Web Server Architectures in Realistic Environments*
Takashi Shinozaki, Eiji Kawai, Suguru Yamaguchi, Heiichi Yamamoto (Nara Institute of Science and Technology, Japan) 169
5. *Extended Role-Based Sensor Mangement Framework*
Soyoung Kim, Mikyeong Moon, Keunhyuk Yeom (Pusan National University, Korea) 175

Session 2A: CDMA & Wireless Communications (II)

1. *The Scheme to Improve the Performance of Initial Ranging Symbol Detection with Common Ranging Code for OFDMA Systems*
Ki-Nam Kim, Jin-Ho Kim, Seong-Chul Kim, Sung-Joon Cho (Graduate School of Hankuk Aviation University, Korea) 183
2. *Physical Layer Analysis of Emerging IEEE 802.11n WLAN Standard*
Josip Lörincz, Dinko Begušić (University of Split, Croatia) 189
3. *Adaptive Modulation and Coding on Multipath Rayleigh Fading Channels Based on Channel Prediction*
Duho Rhee, Jung Hyung Kwon, Hae Kwang Hwang, Kwang Soon Kim (Yonsei University, Korea) 195
4. *SC/FDE with Constant Phase Modulation combined with CDMA and MIMO*
Tufik Buzid, Steffen Reinhardt, Mario Huemer (University of Erlangen-Nuremberg, Germany), Ihan Martoyo (University of Karlsruhe, Germany) 200
5. *Low-Complexity User Selection Strategies in the Downlink of Muti-User Channels*
Mingguang Xu, Dong Lin (Tsinghua University, China) 204

Session 2B: Mobile Communications (II)

1. *On Construction of the Virtual Backbone in Wireless Mesh Networks*
Deepesh Man Shrestha, Young Bae Ko (Ajou University, Korea) 209

2. An Internet Framework to Bring Coherence Between WAP and HTTP Ensuring Better Mobile Internet Security	
Al-Mukaddim Khan Pathan, Md. Abdul Mottalib (Islamic University of Technology, Bangladesh), Minhaz Fahim Zibran (University of Lethbridge, Canada)	215
3. Third Party Call Control in IMS using Parlay Web Service Gateway	
Jong-choul Yim, Young-il Choi, Byung-sun Lee (ETRI, Korea)	221
4. 1xEV-DO 3G Mobile Experimental System Project Report with a Local Market Analysis	
Ren Gang (Sichuan University, China), Chen Binghai (China UNICOM, China)	225
5. Development of Identification System of Wire or Wireless Dispatcher based on Personal LBS	
Dal Hwan Yoon, Yen Tae Jung, Dong Ju Bae, Jeong Wha Heo (Semyung University, Korea)	231

Session 2C: Multimedia and Internet Systems and Services (II)

1. Implementation Issues of a Push Event Delivery Mechanism for Web Content Service Synchronized with TV Programs	
Hisao Tanaka, Eiji Kawai, Suguru Yamaguchi, Heiichi Yamamoto (Nara Institute of Science and Technology, Japan)	237
2. Fast 2D Both Hands Tracking with Articulate Motion Prediction	
Hyejin Kim, Keun-Chang Kwak, Jaeyeon Lee (ETRI, Korea)	243
3. A Study on Design and Implementation of XCAP Server	
Wook Hyun, Sunok Park, Iljin Lee, Shingak Kang (ETRI, Korea)	249
4. Blind Watermarking for Copyright Protection of 3D CAD Drawing	
Ho-Kyun Park (Pusan University of Foreign Studies, Korea), Suk-Hwan Lee (TongMyung University of Information Technology, Korea), Ki-Ryong Kwon (Pusan University of Foreign Studies, Korea)	253
5. A Simple and Fast On-Line Evaluation System for Learning	
Tung-Shou Chen, Rong-Chang Chen, Kuei-Ching Lin, Xin-Yan Wu (NTIT, Taiwan)	257

Session 2D: Next Generation Network Technology (II)

1. Intelligent Network Services in Migration from PSTN toward NGN	
Mahmoud Saeidi, Mahmoud Pirhadi, Fattaneh Ayazi (Iran Telecommunication Research Center, Iran) ...	265
2. Presence-based Call Reservation Service using Open API on the Web-service architecture in Broadband Converged Network	
Yoo-mi Park, Young-il Choi (ETRI, Korea), Sang-ha Kim (Chungnam National University, Korea)	270

3. Web Services Hybrid Dynamic Composition Models for Ubiquitous Computing Networks	
Dhavalkumar Thakker, Taha Osman, David Al-Dabass (Nottingham Trent University, United Kingdom)	274
4. Cooperative Diversity with Selection Combining in Rayleigh Fading for Wireless Ad-hoc Networks	
Nam-Soo Kim, Young-Sang Kim (Cheongju University, Korea)	281
5. Comparative Studies of Address Lookup Algorithms for IPv6	
Yiu Keung Li, Derek Pao (City University of Hong Kong, China)	285

Session 2E: Information Security Technology (II)

1. Security Points for BcN Infrastructure	
Yang-seo Choi, Dong-il Seo, Jong-su Jang (ETRI, Korea)	293
2. A Lightweight IPsec Adaptation for Small Devices in IP-based Mobile Networks	
Jun-Cheol Park, Ah-Hyun Jun (Hongik University, Korea)	298
3. A Comparative Study of Security Protocols Validation Tools: HERMES vs AVISPA	
Mureed Hussain, Dominique Seret (Paris 5 University, France)	303
4. The Design of IPsec Application for IXDP2851	
Minho Han, Kiyoun Kim, Jongsoo Jang (ETRI, Korea)	309
5. Defense against Lap-top Class Attacker in Wireless Sensor Network	
Md. Abdul Hamid, Md. Mamun-Or-Rashid, Choong Seon Hong (Kyung Hee University, Korea)	314

Session 2F: RFID & USN Technologies (II)

1. An Experimental Testbed for Parcel Handling with RFID Technology	
Yonghoon Choi, Jong Un Won, Jong Heung Park (ETRI, Korea)	321
2. Collaborative Detection and Agreement Protocol for Routing Malfunctioning in Wireless Sensor Networks	
Ali Kashif Bashir, Ali Hammad Akbar, Shafique Ahmad Chaudhary, Chauhdary Sajjad Hussain, Ki-Hyung Kim (Ajou University, Korea)	327
3. Mobile Enabled Large Scale Wireless Sensor Networks	
Canfeng Chen, Jian Ma (Nokia Research Center, China)	333
4. An Approach about Implementation and Use of One-Stop Healthcare Service System Using RFID Technology	
Sun-Jin Kim, Nae-Su Kim (ETRI, Korea)	339

5. A Nano Operating System for Wireless Sensor Networks

Seungmin Park, Jin Won Kim, Kee-Young Shin (ETRI, Korea), Daeyoung Kim (CNU, Korea) 345

Session 2G: System and Software Engineering (II)

1. Preliminary Design for Satellite Mission Operation from Mission Request to Command Planning

In Jun Kim, Soojeon Lee, Won Chan Jung, Jaehoon Kim (ETRI, Korea) 351

2. An ECA Rule-based Task Programming Language for Ubiquitous Environments

Kang-Woo Lee (ETRI, Korea), Eun-Sun Cho (Chungbuk National University, Korea), Hyun Kim (ETRI, Korea) 357

3. The Unified Modeling Language-Based Modeling of GMPLS Networks

Sudip Misra (Cornell University, USA), Subhas C. Misra (Super Net Solutions, Canada), Isaac Woungang (Ryerson University, Canada) 361

4. Verifying Software Streaming Systems

Ki-Hyuk Nam (ETRI, Korea), Jun-Kil Park, Jin-Young Choi (Korea University, Korea), Jeong-Joon Lee (Korea Polytechnic University, Korea), Wan Choi (ETRI, Korea) 367

5. Supporting Intra-Site Automatic Tunnel Addressing Protocol with a Network Processor

Byung-yeob Kim, Hyoungjun Kim (ETRI, Korea) 372

Session 3A: CDMA & Wireless Communications (III)

1. A Novel Blind Trms Estimation Method for Wireless OFDM Systems

Athanasios Doukas, Grigorios Kalivas (University of Patras, Greece) 379

2. Real-Valued Self-Orthogonal Finite-Length Sequences with Maximum Absolute Value Less than 2

Peng Shao, Yoshihiro Tanada (Yamaguchi University, Japan) 383

3. A Study on a Comprehensive Protection Ratio Calculation Applicable to Initial Planning for Frequency Coordination in the Fixed Wireless Networks

Kyoung-Whoan Suh (Kangnam University, Korea), Joohwan Lee (ETRI, Korea) 388

4. A Novel OFDM Frequency Offset Estimation

Bo Hong, Xin'an Wang, Gaofa Xiao (Peking Univeristy, China) 393

5. A Timing Synchronization of OFDMA-TDD Systems over Multipath Fading Channels

Hyundong Kim, Sangho Choe (The Catholic University of Korea, Korea) 398

Session 3B: Mobile Communications (III)

1. Scenario Decomposition based Analysis of Next Generation Mobile Services

Dongchun Shin (Chung-Ang University, Korea), Jinbae Kim (Anyang Techn. College, Korea), Seungwan Ryu (Chung-Ang University, Korea), Donsung Oh (ETRI, Korea), Joowan Lee, Minhyung Kang (Chung-Ang University, Korea) 403

2. Experiment of IMS Core Network enabling Ubiquitous Network

Moo Wan Kim (Tokyo University of Information Sciences, Japan), Kwang Sik Kim (GlobeTech Corp., Seoul) 409

3. New Call Admission Control Mechanisms Considering Adaptive Modulation Control

SungKee Noh, SeungWoo Hong, YoungHa Hwang, ByongHo Yae (ETRI, Korea) 413

4. Design and Implementation of Anycast Protocols for Mobile Ad-hoc Networks

Chyi-Ren Dow, Pa Hsuan, Shiow-Fen Hwang (Feng Chia University, Taiwan) 419

5. Directional Shadow Registration Algorithm for Efficient Cluster Mobility in Mobile Ad Hoc Networks

Keun-Ho Lee, Sang-Bum Han (Korea University, Korea), Heyi-Sook Suh (Ministry of Education & Human Resources Development, Korea), Chong-Sun Hwang (Korea University, Korea) 425

Session 3C: Multimedia and Internet Systems and Services (III)

1. An Integrated Web-Based System for Two-Dimensional Electrophoresis Gel Images

Tung-Shou Chen, Tian-Shing Wang, Mao-Chuan Hsiao, Chun-Wei Tsai (NTIT, Taiwan) 433

2. An Efficient Text Filter for Adult Web Documents

Youngsoo Kim, Taekyoung Nam (ETRI, Korea) 438

3. Adaptive Spam Mail Filtering Using Genetic Algorithm

Usarat Sanpakdee, Aranya Walairacht, Somsak Walairacht (King Mongkut's Institute of Technology Ladkrabang, Thailand) 441

4. Human Activity Description Using Motion Verbs in WordNet

Miyoung Cho, Dan Song (Chosun University, Korea), Pankoo Kim (Cheju University, Korea) 446

5. PCA in Wavelet Domain for Face Recognition

Wayo Puyati, Somsak Walairacht, Aranya Walairacht (King Mongkut's Institute of Technology Ladkrabang, Thailand) 450

Session 3D: Next Generation Network Technology (III)

1. *Improving Performance of TCP Vegas for High Bandwidth-Delay Product Networks*
Yi-Cheng Chan, Chia-Liang Lin (National Changhua University of Education, Taiwan), Chia-Tai Chan
(National Yang-Ming University, Taiwan), Cheng-Yuan Ho (National Chiao Tung University, Taiwan) ... 459
2. *NGN Architecture for IPTV Service without Effect on Conversational Services*
Jeongyun Kim, Jinho Hahm, Youngsun Kim (ETRI, Korea), Junkyun Choi (ICU, Korea) 465
3. *An Encoding Scheme for TCAM-Based Packet Classification*
Derek Pao, Yiu Keung Li, Peng Zhou (City University of Hong Kong, China) 470
4. *Smart Window-adjustment for XCP's Congestion Management*
Yuan-Rung Yang (National Chiao Tung University, Taiwan), Chia-Tai Chan (National Yang-Ming University,
Taiwan), Yaw-Chung Chen (National Chiao Tung University, Taiwan), Yi-Cheng Chan (National Changhua
University of Education, Taiwan) 476
5. *Efficient End-to-End QoS Mechanism Using Egress Node Resource Prediction in NGN
Network*
Se Youn Ban, Jun Kyun Choi, Hyong-Soon Kim (ICU, Korea) 480

Session 3E: Information Security Technology (III)

1. *DRM Enabled P2P Architecture*
Jae-Youn Sung (UST, Korea), Jeong-Yeon Jeong, Ki-Song Yoon (ETRI, Korea) 487
2. *TAKCS: Threshold Authentication Key Configuration Scheme for Multilayer Cluster in Mobile
Ad Hoc Networks*
Keun-Ho Lee, Chong-Sun Hwang (Korea University, Korea) 491
3. *Extending TLS for Trust Delegation in Home Networks*
Mureed Hussain, Dominique Seret (Paris 5 University, France) 497
4. *User Authentication Mechanism using Authentication Server in Home Network*
Yun-kyung Lee, Hong-il Ju, Jee-hye Park, Jong-wook Han (ETRI, Korea) 503
5. *The Expansion of Key Infection Model for Dynamic Sensor Network*
Young-Sik Hwang (University of Science & Technology, Korea), Seung-Wan Han, Taek-Yong Nam (ETRI, Korea) ... 507

Session 3F: RFID & USN Technologies (III)

1. *Bedside Sensor Platform Architecture for UbiSAS in Ubiquitous Sensor Network*
Yoon-Sik Yoo, Jae-Doo Huh (ETRI, Korea) 515

2. A Study on the Implementation of the IEEE1451 on a Biomedical Sensor Network for e-Health	
Jaehwan Kim, Keumsang Lim, Jungil Hu, Wooshik Kim (Sejong University, Korea)	519
3. Optimal Coverage Deployment for Wireless Sensor Networks	
Yung-Tsung Hou, Tzu-Chen Lee, Bing-Chiang Jeng, Chia-Mei Chen (National Sun Yat-Sen University, Taiwan)	523
4. A Design and Implementation of Wireless Sensor Network Routing on Nano-Qplus Platform	
Heeseok Choi, Ilgon Park, Youngsam Shin, Seungmin Park (ETRI, Korea)	528
5. Reliable Data Aggregation Protocol for Ad-hoc Sensor Network Environments	
Sang-ryul Shin, Jong-il Lee, Jang-woon Baek, Dae-wha Seo (Kyungpook National University, Korea)	531

Session 3G: System and Software Engineering (III)

1. APROV-SL: A Specification Language of Another Program Verifier	
Taeho Kim (ETRI, Korea), Oukseh Lee (Hanyang University, Korea), Chaedeok Lim (ETRI, Korea)	537
2. Using Tropos to Model Quality of Service for Designing Distributed Systems	
Subhas C. Misra (Super Net Solutions, Canada), Sudip Misra (Cornell University, USA), Isaac Woungang (Ryerson University, Canada), Prabhat Mahanti (University of New Brunswick, Canada)	541
3. A Solution for Automated Auctioning of Idle Telecom Routes	
J.C. Senanayake, J.A.K. Mascranghe (Informatics International Limited, Sri Lanka)	547
4. Test System for Device Drivers of Embedded Systems	
Yu-Seung Ma, ChaeDeok Lim (ETRI, Korea)	550
5. Design and Development of an User Agent for Streaming Lectures – A South African Case Study	
Nyaladzi Mpopu (University of Fort Hare, South Africa), Alfredo Terzoli (Rhodes University, South Africa), Hippolyte Muyungi, G.S.V.Radha Krishna Rao (University of Fort Hare, South Africa)	553

Session 4A: CDMA & Wireless Communications (IV)

1. Pulse Design in UWB Communications using Nyquist Criterion	
Won Mee Jang (University of Nebraska, USA)	559
2. A Self-Tuning Contention Resolution Scheme for IEEE 802.11 Wireless LAN	
Jin Boo Kim, Jeong Ho Kim, Young Ah Song, Jeong Geun Kim (Kyung Hee University, Korea)	565

3. Image and Its Noise Removal in Nakagami Fading Channels	
Xu Huang (University of Canberra, Australia), Allan C. Madoc (University of Melbourne, Australia)	570
4. Dynamic Frequency Selection in OFDMA	
Yueqin Chen, SungHwan Shon, Sang-Jo Yoo, Jae Moun Kim (Inha University, Korea)	574
5. Multilayer Coding Scheme Used in MBC	
Rong Sun, Jingwei Liu, Xinmei Wang (Xidian University, China)	579

Session 4B: Mobile Communications (IV)

1. A Dynamic State Management Algorithm for Overloaded Systems	
Kyoung Seok Lee, Byung-Han Ryu (ETRI, Korea), Cheol-Hoon Lee (Chungnam National University, Korea)	585
2. Receiver Initiated Algorithm for Multi-Hop Ad Hoc Networks	
Bui Ki Chan, Sammy Chan, Derek Pao (City University of Hong Kong, China)	588
3. Movement Detection Mechanism Using Differential RSSI in Mobile MPLS Network	
YoungHwan Kwon (ICU, Korea), Seong Gon Choi (Chungbuk National University, Korea), Jun Kyun Choi (ICU, Korea)	594
4. A Proficient Path Selection for Wireless Ad Hoc Routing Protocol	
A N Al-Khwardi, H S Al-Raweshdy (Brunel University, United Kingdom)	599
5. An Adaptive Dynamic Scheme For A Dynamic Paging Performance In Hierarchical Mobile IPv6	
Sunyoung Lee, Jongwon Choe (Sookmyung Women's University, Korea)	605

Session 4C: Multimedia and Internet Systems and Services (IV)

1. Authoring System for Interactive Multi-View Visual Contents	
Injae Lee, Myungsuk Ki, Seyoon Jeong, Kyuhea Kim (ETRI, Korea)	613
2. QoSIP: A QoS Aware IP Routing Protocol for Multimedia Data	
Md. Golam Shagadul Amin Talukder (Metropolitan University, Bangladesh), Al-Mukaddim Khan Pathan (Islamic University of Technology, Bangladesh)	618
3. Travel Ontology for Recommendation System based on Semantic Web	
Chang Choi, Miyoung Cho (Chosun University, Korea), Eui-young Kang (Cheju National University, Korea), Pankoo Kim (Chosun University, Korea)	624

4. An Integrated Virtual Instrumentation System Using Statistical Process Control and ImageProcessing	
Puo-Iang Chen, Chung-Wei Huang, Tung-Shou Chen (National Taichung Institute of Technology, Taiwan)	628
5. Ontology-Based Context-Aware Service Engine for U-Healthcare	
Eun-Jung Ko, Hyung-Jik Lee, Jeon-Woo Lee (ETRI, Korea)	632

Session 4D: Next Generation Network Technology (IV)

1. Design and Implementation of Recursive DNS Server	
Tony Bonanno, HyoungJun Kim, Jungsoo Park (ETRI, Korea)	641
2. Comparison of Handover schemes for Next Generation Networks	
Jongmin Lee, Myoungju Yu, Seong-gon Choi (Chungbuk National University, Korea), Eunah Kim, Junghoon Lee (ETRI, Korea)	645
3. QoS in I-MPLS-based Heterogeneous Networks	
René Böringer, Andreas Mitschele-Thiel (Technische Universität Ilmenau, Germany), Gunnar Scharfe (IDEO Laboratories GmbH, Germany)	650
4. DiffProbe: One way Delay Measurement for Asynchronous Network and Control Mechanism in BcN Architecture	
Jongtae Song, Soon Seok Lee, Young Sun Kim (ETRI, Korea)	656
5. A Framework for Absolute End-to-End Delay Guarantee Based on ADRR Scheduler	
Kyung-Min Lee, Hong-Shik Park (ICU, Korea), Soon-Seok Lee, Jae-Young Ahn (ETRI, Korea)	662

Session 4E: Information Security Technology (IV)

1. Implementation of VPN Router Hardware Platform using Network Processor	
Sang-Woo Lee, Yong-Sung Jeon, Ki-Young Kim, Jong-Soo Jang (ETRI, Korea)	671
2. Signature Systems on Smart Card with Keys Generated by Fingerprint	
Lin You (Beijing University of Aeronautics and Astronautics, China), Maozhi Xu (Peking University, China), Qibin Hou (Beijing University of Aeronautics and Astronautics, China)	675
3. High-Speed Attack Mitigation Engine by Packet Filtering and Rate-limiting using FPGA	
Sang-Kil Park, Jin-Tae Oh, Jong-Soo Jang (ETRI, Korea)	680
4. IPSec Overhead Analysis in Dual Stack IPv4/IPv6 Transition Mechanisms	
M. Mujinga , Hippolyte Muyingi, G.S.V.R.Krishna Rao (University of Fort Hare, South Africa)	686

5. Study on the Design of MDS-M2 Twofish Cryptographic Algorithm adapted to Wireless Communication	
Pil-Joong Kang, Seon-Keun Lee, Hwan-Yong Kim (Wonkwang University, Korea)	692

Session 4F: RFID & USN Technologies (IV)

1. REMS and RBPTS: ALE-compliant RFID Middleware Software Platform	
Taesu Cheong, Youngil Kim, Yongjoon Lee (ETRI, Korea)	699
2. Smartening the Environment using Wireless Sensor Networks in a Developing Country	
Al-Sakib Khan Pathan, Choong Seon Hong (Kyung Hee University, Korea), Hyung-Woo Lee (Hanshin University, Korea)	705
3. Self-Encoded TH-PPM UWB System with Iterative Detection	
Youn Seok Kim, Won Mee Jang, Lim Nguyen (University of Nebraska, USA)	710
4. NanoEsto Debugger: The Tiny Embedded System Debugger	
In-geol Chun, Chae-deok Lim (ETRI, Korea)	715
5. Opportunistic Scheduling with Power Control in Ad Hoc Wireless Networks	
Reizel Casaquite (Inje University, Korea), In-Yeup Kong (Pusan National University, Korea), Myung-Hyun Yoon (Korea Electronics Technology Institute, Korea), Won-Joo Hwang (Inje University, Korea)	719

Session 4G: System and Software Engineering (IV)

1. A Dynamic Load Balancing Model For Networked Virtual Environment Systems Using an Efficient Boundary Partition Management	
Jung Youl Lim, Jin Ryong Kim, Kwang Hyun Shim (ETRI, Korea)	727
2. Fast Soft Decision Decoding Based on Error Weights	
Chang-Wei Wu, Hsin-Kun Lai, Erl-Huei Lu (Chang Gung University, Taiwan)	731
3. Code Generation for Linux Device Driver	
Yong Hoon Choi, Woo Il Kwon, Heung Nam Kim (ETRI, Korea)	734
4. Single Measure Similarity for Spatial Data Management System	
Lau Bee Theng, Wang Yin Chai (Swinburne University of Technology Sarawak, Malaysia)	738
5. Data Fusion Applied on Autonomous Ground Vehicles	
Emanuel Taropa, Vason P. Srini, Won-Jong Lee, Tack-Don Han (Yonsei University, Korea)	744

Session 4H: Poster Session (I)

1. Skimmer-shaped Linear Polarized Circular Microstrip Antennas for Miniaturization	
Mi-ra Ryu (Konkuk University, Korea), Jong-Myung Woo (Chungnam National University, Korea), Jung Hur (Konkuk University, Korea)	755
2. Fast Handover Scheme Based on Enhanced Access Point (EAP) for Mobile IPv6	
Byungjoo Park, Haniph Latchman (University of Florida, USA)	759
3. Embedded and Scalable Image Coding Based on Virtual SPIHT	
Chen Hongxin, Liu Zhengguang (Tianjin University, China)	764
4. A Study of Performance Improvement on the End-host through Diagnosis of System Metrics	
Kook-han Kim, Jong-ho Ryu, Dong-il Seo (ETRI, Korea)	769
5. New Protocol Design for Wireless Networks Security	
Gamal Selim (Arab Academy for Science & Technology, Egypt), Hesham M. El Badawy (National Telecommunication Institute, Egypt), Mohamed Abdul Salam (Arab Academy for Science & Technology, Egypt)	773
6. Redundant Multiprocessor Interconnects for the High Capacitor Router Built on ATCA	
Bup-Joong Kim, Woo-Young Choi, Hak-Suh Kim, Byungjun Ahn (ETRI, Korea)	777
7. Subspace Separator and Functional Link Neural Network Based Receiver for DS-CDMA Signal	
Chengliang Li, Weiyu Zheng (Carleton University, Canada)	782
8. Design and Implementation of Linux-based Application which supports CDMA and WiBro network	
Dohyung Kim, Minhong Yun, Sunja Kim (ETRI, Korea), Cheol-Hoon Lee (Chungnam National University, Korea)	786
9. A New Collision-free Media Access Protocol for Metro OBS Ring Networks	
Sunghoon Jung, Minhoo Kang (ICU, Korea)	790
10. A Case Study using Open API on BCN: E-Business card service	
Kisoon Sung, Yongil Choi (ETRI, Korea)	793
11. Incorporating Intrusion Detection Functionality into IXP2800 Network Processor based Router	
Seungho Ryu, Bo-Heung Chung, Ki-Young Kim (ETRI, Korea)	797
12. Security Vulnerability and Considerations in Mobile RFID environment	
Juhan Kim, Howon Kim (ETRI, Korea)	801
13. RS decoder architecture for UWB	
Sung-Woo Choi, Sang-Sung Choi, Han-ho Lee (ETRI, Korea)	805

14. Improved WBAN Communication at Mental Healthcare System with the Personalized Bio Signal Devices	
JY Jung, JW Lee (ETRI, Korea)	809
15. Dynamic Bandwidth Allocation with Minimum Long Fluctuations	
Ali Reza Shams Shafigh, Forough Noroozi, Zahra Abbasi, Hamid Reza Khodabandeh (Iran Telecommunication Research Center, Iran)	813
16. Color Descriptor for Image Retrieval in Wavelet Domain	
Ariya Utenpattanan, Orachat Chitsobhuk, Amnach Khawne (King Mongkut's Institute of Technology Ladkrabang, Thailand)	818
17. Virtual Route Scheme for Preventing Authentication Bypass in the WWW Environment	
Seung-Hyun Kim, Seung-Hun Jin (ETRI, Korea)	822
18. A Remote Diagnostic Tool for USB Kernel Resources in the Embedded Linux Systems	
Jeong-Si Kim, ChaeDeok Lim (ETRI, Korea)	828
19. A CMOS Variable Gain Amplifier with Wide Dynamic Range and Accurate dB-Linear Characteristic	
Ji-Hun Kim, Chang-Seok Chae, Young-Jin Woo, Gyu-Hyeong Cho (KAIST, Korea)	831
20. Basic Call Flow for Interoperability Test in the Presence Services based on SIP	
MiYoung Huh, SunOk Park, Wook Hyun, JaeChon Han, IlJin Lee, ShinGak Kang (ETRI, Korea)	836
21. Design of a 13.56MHz RFID System	
Nak-Gwon Choi, Hyuek-Jae Lee, Sang-Hoon Lee, Seong-jeen Kim (Kyungnam University, Korea)	840
22. A Load Testing Architecture for Networked Virtual Environment	
Bum Hyun Lim, Jin Ryong Kim, Kwang Hyun Shim (ETRI, Korea)	844
23. PN Code Acquisition Using Signed-Rank-Based Detector in Non-Gaussian Impulsive Channels	
Dahae Chong, Byeongyun Lee, Sanghun Kim, Seokho Yoon (Sungkyunkwan Univeristy, Korea), Sun Yong Kim (Konkuk University, Korea)	849
24. Method for Performing an Address Resdolution Protocol on EoS	
Hae Sook Jeon, Tae Il Kim (ETRI, Korea)	854
25. Privacy Protection based on User-defined Preferences in RFID System	
Inseop Kim, Byunggil Lee, Howon Kim (ETRI, Korea)	858
26. The RFID Middleware System Supporting Context-Aware Access Control Service	
Jieun Song, Howon Kim (ETRI, Korea)	863
27. UWB Communication and Networking Systems with Chaotic Oscillator for Low Rate WPAN	
Cheolhyo Lee, Jae-Young Kim (ETRI, Korea)	867

28. Performance Analysis of Satellite Payload Antenna Design Result	
Jeom-Hun Lee, J-S Choi, Jae-Hoon Kim, S-P Lee (ETRI, Korea), Seung-hyeub Oh (Chungnam National University, Korea)	871
29. Design of the Network Control System for OBS Satellite Communications System	
Kyung Soo Choi, Jin Ho Jo, Cheon Sig Sin, Seong Pal Lee (ETRI, Korea)	875
30. A Visual Feature based Video Identifying System for the TV Commercial's Monitoring	
Sung Hwan Lee, Won Young Yoo, Young Suk Yoon (ETRI, Korea)	880
31. Technical Standardization Status and the Advanced Strategies of the Next Generation Mobile Communications	
Joo Seong Park, Hyo Jun Lee, Mintaig Kim (ETRI, Korea)	884
32. Adaptive Threshold-based Link Status Update Mechanism	
Tae-IL Kim, Jeong-Ju Yoo, Hae-Won Jung, Hyeong-Ho Lee (ETRI, Korea), Min Young Chung (Sungkyunkwan University, Korea), Seong-IL Jin (ChungNam National University, Korea)	888
33. Optimizing Hash Table Structure of Flow Exporting Software	
Woo-jin Yang, Tae-il Kim, Hae-won Jung (ETRI, Korea)	892
34. Application of Control Theory in QoS Control	
Dang-Hai Hoang (PTIT, Vietnam)	896

Author Index

Volume II

Session 5A: CDMA & Wireless Communications (V)

1. The BER Performance of a Quasi-Orthogonal Minimum Output Energy Multiuser Detector for CDMA Systems in Nakagami Environment	
Mohamed Moustafa Abd-El Aziz Moustafa (Thebes Academy, Egypt)	905
2. A Study on Bandwidth Broadening of Dual-Band Slot Antenna using Matching Patch	
Tae Soon Chang, Sang Won Kang, Jong Ye Leem (Konkuk University, Korea), Baek Bong Pyo (LG Electronics, Korea) , Jung Hur (Konkuk University, Korea)	910

3. Propagation Characteristics of UWB Radio in a High-Rise Apartment	
Simon S.M. Wong (Hong Kong SAR Government, China), Francis C.M. Lau, Chi K. Tse (Hong Kong Polytechnic University, China)	914
4. A Novel Cyclic-Shifted Preamble Scheme for Symbol Synchronization Based on OFDM WLANs	
Xiang Zhao, Myoung-Seob Lim (Chonbuk University, Korea)	919
5. ROI-based Joint Source -Channel Coding for Wireless Video Transmission	
Zhenming Zhang, Guangxi Zhu, Feng Wang, Lei Xie (HuaZhong University of Science & Technology, China)	923

Session 5B: Mobile Communications (V)

1. Performance Analysis of An Efficient QoS Scheme over IEEE 802.11e Based Wireless Access Networks	
Moonsik Kang (Kangnung National University, Korea)	929
2. An Approach for Optimal System Selection for the ISHO in Future Convergence Network	
Hung Ngoc Le, Quynh Xuan Nguyen (PTIT, Vietnam), Sung Gu Choi, Yeon Seung Shin (ETRI, Korea)	934
3. An Adaptive Routing Protocol Selection Algorithm Corresponding to Dynamic Wireless Network Environment	
Ming-Shen Jian, Ta-Yuan Chou, Chungnan Lee (National Sun Yat-Sen University, Taiwan)	939
4. A Fast Handover Mechanism for IPv6 Based WiBro System	
Minsik Shim, Hwasung Kim (Kwangwoon University, Korea), Sangho Lee (ETRI, Korea)	945
5. Considerations of Neighbor Discovery Protocol over IEEE 802.16 Networks	
Joo-Chul Lee (ETRI, Korea), Youn-Hee Han (Samsung Advanced Institute of Technology, Korea), Myung-Ki Shin (ETRI, Korea), Hee-Jin Jang (Samsung Advanced Institute of Technology, Korea), Hyoung-Jun Kim (ETRI, Korea)	951

Session 5C: Multimedia and Internet Systems and Services (V)

1. Implementation of High Performance Objectionable Video Classification System	
Hogyun Lee, Seungmin Lee, Taekyong Nam (ETRI, Korea)	959
2. Complexity Scalable Inter Modes Decision Algorithm for H.264 Based on Spatial Correlation	
Bin Feng, Guang-xi Zhu, Wen-yu Liu (Huazhong University of Science and Technology, China)	963

3. Temporal Scene Management for Interactive Virtual Storytelling	
Seulki Kang, Heedong Ko (Korea Institute of Science and Technology, Korea), YoonChul Choy (Yonsei University, Korea)	967
4. Image Registration using Hough Transform and Phase Correlation	
Siwaphon Chunhavitayatera, Orachat Chitsobhuk, Kiatnarong Tongprasert (King Mongkut's Institute of Technology Ladkrabang, Thailand)	973
5. The Design of Digital Items Server for Processing Multi DI Clients on Ubiquitous Environments	
Choon Seo Park, Jung-Keun Kim, Jin-Hwan Jeong, YongJu Lee, Ok-Gee Min, Hag-Young Kim (ETRI, Korea)	978

Session 5D: Next Generation Network Technology (V)

1. The Role of Ethernet over SDH in QoS Switch/Router	
Hong Ju Kim, Seong il Myong, Hyun Ha Hong, Jong Hyun Lee, Jung Sik Kim (ETRI, Korea)	985
2. Performance Comparison of Existing Mobility Management Schemes for NGN	
Myoung Ju Yu, Jong Min Lee, Seong Gon Choi (Chungbuk National University, Korea), Eunah Kim, Junghoon Jee (ETRI, Korea)	991
3. QoS-Aware Fair Scheduling in Multihop Wireless Ad Hoc Networks	
Muhammad Mahbub Alam, Md. Abdul Hamid, Choong Seon Hong (Kyung Hee University, Korea)	996
4. Presence Service Middleware Architecture for NGN	
Sung Bo Yang (ICU, Korea), Sung Gon Choi (CBNU, Korea), Se Yun Ban (ICU, Korea), Yoo-Jung Kim (NCA, Korea), Jun Kyun Choi (ICU, Korea)	1001
5. Design and Implementation of Adaptive Service Edge Router	
Eunah Kim, Woojik Chun (Raonet Systems, Inc., Korea), Lee Yoo Kyoung (ETRI, Korea)	1004

Session 5E: Information Security Technology (V)

1. Design of Giga Performance VPN Router	
Sang Su Lee, Sang Woo Lee, Yong Sung Jeon, Ki Young Kim (ETRI, Korea)	1011
2. A Secure LSB Steganography System Defeating Sample Pair Analysis Based on Chaos System and Dynamic Compensation	
Xiangyang Luo, Zongyun Hu, Can Yang, Shanqing Gao (Zhengzhou Information Science and Technology Institute, China)	1014

3. Access Control for Middleware in RFID Systems	
Taesung Kim, Howon Kim (ETRI, Korea)	1020
4. Design and Development of Network Intrusion Detection System Detection Scheme on Network Processing Unit	
Robin Salim, G.S.V. Radha Krishna Rao (Multimedia University, Malaysia)	1023
5. The Design of Key Security in Ethernet PON	
Jee-Sook Eun, Yool Kwon (ETRI, Korea)	1026

Session 5F: RFID & USN Technologies (V)

1. Design and Implementation of Mobile RFID Technology in the CDMA Networks	
Myunghee Son, Yongjoon Lee, Cheolsig Pyo (ETRI, Korea)	1033
2. Battery Model for Wireless Networks using Photovoltaic cells	
John Paul M. Torregoza, In-Yeop Kong, Won Joo Hwang (Inje University, Korea), Jong Gyu Kim (Yeung-Jin College, Korea)	1037
3. Security in Wireless Sensor Networks: Issues and Challenges	
Al-Sakib Khan Pathan (Kyung Hee University, Korea), Hyung-Woo Lee (Hanshin University, Korea), Choong Seon Hong (Kyung Hee University, Korea)	1043
4. A Network Reference Model for B2C RFID Applications	
Yong-Woon Kim, Jun-Seob Lee, Sang-Keun Yoo, Hyoung-Jun Kim (ETRI, Korea)	1049
5. RFID Code Structure and Tag Data Structure for Mobile RFID Services in Korea	
Jun Seob Lee, Hyoung Jun Kim (ETRI, Korea)	1053

Session 5G: Optical Networking Technology (I)

1. An Algorithm and a Tool for Wavelength Allocation in OMS-SP Ring Architecture	
Tahir M. Riaz, Jens M. Pedersen, Ole Madsen (Aalborg University, Denmark)	1059
2. A New DBA Scheme to Improve Bandwidth Utilization in EPONs	
Dong-yeal Lee (DACOM Corp., Korea), Seung-hyeub Oh (Chungnam National University, Korea)	1063
3. Modeling of a Step and Linear Shared Buffer using an OOP for Optical Packet Switch	
Mohd Shahril Salleh, Azrin Aris, Romli Mohamad, Kaharudin Dimiyati (Telekom Malaysia R&D, Malaysia)	1068
4. An Application of a Smart Optical Amplifier to the Bidirectional Transmission	
Bo-Hun Choi (Gwangju University, Korea), Chang-Bong Kim (Kongju National University, Korea)	1074

5. Resilience of Dynamic Traffic in Mobility over WDM Optical Networks	
Chen-Shie Ho (VaNung University, Taiwan)	1080

Session 6A: CDMA & Wireless Communications (VI)

1. Analysis of the Error Probability of a Binary Receiver in Wireless Fading Channels	
Xu Huang, Dharmendra Sharma (University of Canberra, Australia)	1087
2. Throughput Analysis of SR-ARQ Scheme with Adaptive Packet Length in Slowly Varying Rayleigh Fading Channel	
Dong Yang, Wah Ching Lee (Hong Kong Polytechnic University, China)	1091
3. Performance of Quasi-orthogonal Space-Time Block Code over Time-Selective Channel with Linear and Decision Feedback Equalizations	
Youxiang Wang, Jiyu Jin, Yongwan Park (Yeungnam University, Korea)	1095
4. Prediction of Time-Varying Multipath Fading Channel for Pre-equalization of the Signal in Uplink Mobile MC-CDMA Communications	
Gagik Mkrtchyan, Katsuhiro Naito, Kazuo Mori, Hideo Kobayashi (Mie University, Japan)	1101
5. A New Stopping Criterion for Turbo Codes	
Byoung-Sup Shim, Dae-Ho Jeong, Soon-Ja Lim, Hwan-Yong Kim (Wonkwang University, Korea)	1107

Session 6B: Mobile Communications (VI)

1. An Efficient TCP Mechanism to Reduce Out-of-Sequence Packets in Mobile IPv6	
Byungjoo Park, Jongdae Lee, Haniph Latchman (University of Florida, USA)	1115
2. Study of Mobility Control Functions in Ambient Networks	
Shintaro Uno (Motorola Japan, Japan), Jochen Eisl (Siemens Communications, Germany), Ramón Agüero (University of Cantabria, Spain)	1119
3. Case Study : NoC based Next-generation WLAN Receiver Design in Transaction Level	
Sung-Rok Yoon, Jin Lee, Sin-Chong Park (Information and Communications University, Korea)	1125
4. Impact of Group Mobility on Ad hoc Networks Routing Protocols	
Jim M. Ng, Yan Zhang (Nanyang Technological University, Singapore)	1129
5. Local Authentication Mechanism for Micro Mobility in Wireless Active Network Environment	
Insu Kim (Konkuk University, Korea), Keecheon Kim (Nextel Communication, USA)	1135

Session 6C: Multimedia and Internet Systems and Services (VI)

- 1. Design and Implementation of a Storage Management Method for Content Distribution**
Chang Soo Kim, Yu Hyun Bak, Sang Min Woo, Won Jae Lee, Ok Gee Min, Hag Young Kim (ETRI, Korea) 1143
- 2. SDL and MSC Description of ETRI Software Streaming Protocol**
Jeong-Joon Lee (Korea Polytechnic University, Korea), Ki-Hyuk Nam, Wan Choi (ETRI, Korea), Dongho Song (SOFTonNET Inc., Korea), Ki-Suk Kong (Korea Polytechnic University, Korea) 1148
- 3. Designing a New Storage Technique for Face Images Transmission Using JPEG2000**
Hsiu-Mei Huang, Geeng-Neng You, Fu-Song Syu (National Tai-Chung Institute of Technology, Taiwan), Shu-Sheng Liaw (China Medical University, Taiwan) 1152
- 4. Design of an Adaptive Streaming System in Ubiquitous Environment**
Okgee Min, Jungkun Kim, Myoungjoon Kim (ETRI, Korea) 1157
- 5. The Implementaion of ISATAP Router**
Sang-Do Lee, Myung-Ki Shin, Hyoung-Jun Kim (ETRI, Korea) 1161

Session 6D: Broadband Satellite & HAPS

- 1. Enhanced Automatic Gain Control using the Hybrid Gamma Parameter in DVB-S2 System**
Cheon-in Oh, Seung-hyun Choi (UST, Korea), Dae-ig Jang, Duk-kil Oh (ETRI, Korea) 1167
- 2. Improvement of Burst Error Correction Using a Look-Up Table with Low Density Parity Check Coding for Compressed Ultraspectral Sounder Data**
Bormin Huang, Y. Sriraja, Hung-Lung Huang (Space Science and Engineering Center, USA), Mitchell D. Goldberg (NOAA NESDIS, USA) 1172
- 3. IEEE 802.11 Optimisation Techniques for Inter-Satellite Links in LEO Networks**
Kawsu Sidibeh, Tanya Vladimirova (University of Surrey, United Kingdom) 1177
- 4. Analysis on the Performance of the Demodulation Algorithm on the Backward Compatible Modes of DVB-S2**
Seung-hyun Choi, Cheon-In Oh (UST, Korea), Tae-Hoon Kim, Deock-Gil Oh, Dae-Ig Chang (ETRI, Korea) 1183
- 5. Optimum Designing of Amateur Satellite for Maximum Availability**
Pejman Rezaei, Noushin Aboutorabian, Mohammad Hakkak (Tarbiat Modarres University, Iran) 1188

Session 6E: Information Security Technology (VI)

- 1. A Method for Preventing the Leakage of the Personal Information on the Internet**
Daeseon Choi, Seunghun Jin (ETRI, Korea), Hyunsoo Yoon (KAIST, Korea) 1195
- 2. Detection of LTSB Steganography Based on Quartic Equation**
Xiangyang Luo, Qingxian Wang, Chunfang Yang, Fenlin Liu (Information Engineering University, China) 1199
- 3. Key Management Scheme for Providing the Confidentiality in Mobile Multicast**
Jong-Hyuk Roh (ETRI, Korea), Kyoong-Ha Lee (Inha University, Korea) 1205
- 4. Linear Cryptanalysis on Second Round Simplified AES**
S. Davod. Mansoori, Hossein Khaleghi Bizaki (Malek Ashtar University, Iran) 1210
- 5. Analysis of Applicability of Traditional Spam Regulations to VoIP Spam**
So Young Park, Jeong Tae Kim, Shin Gak Kang (ETRI, Korea) 1215

Session 6F: IT Service Technology (I)

- 1. Probabilistic Approach to Model Intelligent Robot Services**
Young Cheol Go, Joo-Chan Sohn, Young-Jo Cho (ETRI, Korea) 1221
- 2. Collaboration Services to Support Interactions in Disaster Relief Scenarios**
Sergio F. Ochoa (University of Chile, Chile), Roberto Aldunate (University of Illinois, USA) 1225
- 3. CAS²: Context Awareness Service System based on Wireless Sensor Networks**
Ilgon Park, Heeseok Choi, Kee-Young Shin, Jinwon Kim, Seungmin Park (ETRI, Korea) 1231
- 4. Experiment of Wireless Ubiquitous Network Service using Parlay**
Moo Wan Kim (Tokyo University of Information Sciences, Japan) 1235
- 5. Dual Journaling Store Method for Embedded Systems**
Jeong-Ki Kim, Hyung-Seok Lee, Heung-Nam Kim (ETRI, Korea) 1241

Session 6G: Optical Networking Technology (II)

- 1. Performance Analysis of the Extra Offset-Time Based QoS Mechanism in TCP over Optical Burst Switching Networks**
Min-Gon Kim, Hongkyu Jeong, JungYul Choi, Ji-Hwan Kim, Minhoo Kang (ICU, Korea) 1247
- 2. A New GMPLS Survivability Mechanism**
Hua Qu, Zengzhi Li (Xi'an Jiaotong University, China), Jihong Zhao (Northwestern Polytechnical University, China) 1252

3. Performance Evaluation of Dynamic Bandwidth Sharing-Based MAC Protocol over WDM/Ethernet-PON	
Bokrae Jung (ICU, Korea), Hyunho Yun, Taeyeon Kim, Jungju Yoo (ETRI, Korea) , Minho Kang (ICU, Korea)	1258
4. Preemptive Hybrid Scheduling Scheme for Optical Packet Switch with Class Differentiation	
G Y. II (University of Malaya, Malaysia), Mohamad Khazani Abdullah (Universiti Putra Malaysia, Malaysia), Kaharudin Dimyati (University of Malaya, Malaysia)	1261
5. Performance Comparisons of Restoration Techniques for Fault Management in OBS Networks	
YoungMin Kim, TaeHwa Kim (ICU, Korea), JungJoo Yoo, Byeong Whi Kim (ETRI, Korea) , HongShik Park (ICU, Korea)	1264

Session 7A: CDMA & Wireless Communications (VII)

1. MIMO Partial Parallel Interference Cancellation for Space Time Block Coded MIMO-CDMA System	
Sunmi Kim, Jaewon Park, Yongwan Park (Yeungnam University, Korea)	1271
2. Performance of Adaptive Modulation in Multipath Fading Channel	
Hadi K Mohammed, Rajeev Tripathi, Krishna Kant (Motilal Nehru National Institute of Technology, India)	1277
3. Adaptive Modulation Technique with Partial CQI for Multiuser OFDMA Systems	
Jung Hyoung Kwon, Duho Rhee, Il Mu Byun (Yonsei University, Korea), Younghoon Whang (IMNetpia, Korea), Kwang Soon Kim (Yonsei University, Korea)	1283
4. The Fuzzy Control Based Multiple Threshold Channel Reservation Scheme for the Integrated UTRA FDD and UTRA TDD Mobile Radio Networks	
Jeich Mar, Shu-Rong Chen, Chi-Cheng Kuo (Yuan-Ze University, Taiwan)	1287
5. Trade-off between Performance and Complexity with various Candidates in LDPC coded MIMO-OFDM Iterative Decoding	
Seongmin Noh, Sin-Chong Park (ICU, Korea)	1291

Session 7B: Mobile Communications (VII)

1. SCTP-based Handoff based on MIH Triggers Information in Campus Networks	
Yung-Mu Chen, Min-Yen Lai, Shao-Chieh Lin, Shao-Chen Chang, Tein-Yaw Chung (Yuan Ze University, Taiwan)	1297

2. Tree-based Admission Control for Mobile QoS in DiffServ Networks	
Jung-Mo Moon, Mi-Young Yun, Sang-Ho Lee (ETRI, Korea)	1302
3. An Efficient Fast Neighbor Discovery (EFND) Scheme to Reduce Handover Latency in Mobile IPv6	
Byungjoo Park (University of Florida, USA), Eunsang Whang (LG Electronics, Korea), Haniph Latchman (University of Florida, USA)	1306
4. Performance Evaluation of WAP Packet Considering WTP SAR Algorithm and RLP in Wireless Network	
Il-Young Moon (Korea University of Technology and Education, Korea)	1311
5. A Novel Analogous Simulation Method with Applications on 3G Mobile System Planning and Optimization	
Ren Gang (Sichuan University, China), Chen Binghai (China UNICOM, China)	1315

Session 7C: Multimedia and Internet Systems and Services (VII)

1. Design and Implementation of SoD Engine for Linux	
Ki-Hyuk Nam, Ji-Su Kim, Won-Young Kim, Jung-Min Shim, Sung-Ju Kang, Sung-Jin Heo, Wan Choi (ETRI, Korea)	1323
2. A Novel Ad Hoc Wireless Multimedia Distribution System: Computer Simulation and System Implementation	
Ren Gang (Sichuan University, China), Xie Jun (Sichuan TV Station, China)	1327
3. Wavelet-based Scalable Video Coding with Low Complex Spatial Transform	
Seongho Park, Hyungsuk Oh, Wonha Kim (Kyung Hee University, Korea)	1333
4. A New Knowledge-Based Face Image Indexing System through the Internet	
Shu-Sheng Liaw (China Medical University, Taiwan), Geeng-Neng You, Fu-Song Syu, Hsiu-Mei Huang (National Tai-Chung Institute of Technology, Taiwan)	1336
5. A CMQ Middleware Architecture for Multimedia Application in Ubiquitous Environment	
Han-Sol Park, Da-Hye Choi, You-Hyeon Jeong, Tae-Uk Choi (ETRI, Korea)	1341

Session 7D: Telematics Technology

1. Development of Open Telematics Service Based on Gateway and Framework	
Chul-Su Kim, Jongik Kim, Woo-Yong Han, Oh-Cheon Kwon (ETRI, Korea)	1349

2. Analysis and Implementation of Interference Analysis System for Effective Use of Radio Spectrum	
Eun Cheol Kim, Jin Young Kim, Jong Heon Kim (Kwangwoon University, Korea)	1353
3. A Nearby Server Selection Protocol based Cross-Shaped Trajectory in Sensor Networks	
In Gu Han (Inha University, Korea), Yeong Hwan Tscha (Sangji University, Korea), Kyoong Ha Lee (Inha University, Korea)	1357
4. A Novel Multipath Mitigation Scheme Based on Slope Difference of Correlator Output for Galileo Systems	
Chulho Lee, Seungsoo Yoo (Konkuk University, Korea), Seokho Yoon (Sungkyunkwan University, Korea), Sun Yong Kim (Konkuk University, Korea)	1360
5. Design and Implementation of Status based Application Manager for Telematics	
Minjung Kim, Yeonjune Choi, YoungBag Moon, Sunjoong Kim, Oh-Cheon Kwon (ETRI, Korea)	1364

Session 7E: Information Security Technology (VII)

1. Identity Based KCDSA Signcryption	
Jong-Ho Ryu, Youn-Seo Jeong, Dong-il Seo (ETRI, Korea)	1369
2. Quantum Signature Scheme with Message Recovery	
Jian Wang, Quan Zhang, Chao-jing Tang (National University of Defence Technology, China)	1375
3. Investigation of Feasible Cryptographic Algorithms for Wireless Sensor Network	
Kyung Jun Choi, Jong-In Song (GIST, Korea)	1379
4. Priority-based High-speed Intelligent Rule-checking	
Saraswathi Sachidananda, Mintu Shah, Srividya Gopalan, Sridhar Varadarajan (Satyam Computer Services Ltd., India)	1382
5. Pairwise Key Establishment Mechanism based on Clustering for Secure Sensor Network	
Inshil Doh, Mihui Kim, Kijoon Chae (Ewha Womans University, Korea)	1388

Session 7F: IT Service Technology (II)

1. Efficient offering Service Creation Experience Environment for Open Service	
Seunghwa Chung, Sangki Kim (ETRI, Korea)	1395
2. A Strategy to Share Documents in MANETs using Mobile Devices	
Andrés Neyem, Sergio F. Ochoa, José A. Pino (University of Chile, Chile)	1400
3. Design of the Automatic Ontology Building System about the Specific Domain Knowledge	
Hyunjang Kong, Myunggwon Hwang, Pankoo Kim (Chosun University, Korea)	1405

4. A Study on Surface Subdivision	
Ahsan Ullah, Koichi Harada (Hiroshima University, Japan)	1409
5. What Should We Watch Over to Adopt RFID for Pharmaceutical Supply Chain in Korea?	
Inkyu Lee, Hajae Chung (ETRI, Korea)	1413

Session 7G: Optical Networking Technology (III)

1. On the Pacing Technique for High Speed TCP over Optical Burst Switching Networks	
Moonsoo Kang, Jeonghoon Mo (ICU, Korea)	1421
2. Application-aware Contention Resolution Scheme for Grid Services over OBS Networks	
Byungsang Kim, Ji-Hwan Kim, Min-Gon Kim, Minhoo Kang (ICU, Korea)	1425
3. Label swapping in All-Optical Networks Using Tunable Fiber Bragg Grating Arrays	
M. Rajabvand, F. Behnia, M. T. Fatehi (Sharif University of Technology, Iran)	1429
4. Optical Buffer-based Service Differentiation in Burst Switching-based Optical Networks	
JungYul Choi, Minhoo Kang (ICU, Korea)	1432
5. IP Service Schemes for Ethernet PON and an EPON Master Chip Designed to Provide Such Services	
Chan Kim, Jeong-Gook Kwon, Tae-Whan Yoo, Yool Kwon, Bong-Tae Kim (ETRI, Korea)	1436

Author Index

Volume III

Session 8A: CDMA & Wireless Communications (VIII)

1. A Non-coherent UWB Ranging for Precision Asset Location with Considering Simultaneously Operating Piconets	
Woon Yong Park (Soongsil University, Korea), Sungsoo Choi (KERI, Korea), Won Cheol Lee (Soongsil University, Korea)	1445
2. Spectral Analysis and Performance Evaluation of One-chip VCXO with the Zig System	
Dal-Hwan Yoon, Dong Ju Bae, Seung Woo Kim, Jeong Su Han (Semyung University, Korea)	1449

3. Simulation of Interference Effects from UWB Sources to A Digital Narrowband Transmission System	
Idnin Pasya, Atsushi Tomiki, Takehiko Kobayashi (Tokyo Denki University, Japan)	1452
4. A Simple Asynchronous UWB Position Location Algorithm Based on Single Round-Trip Transmission	
Dongwoo Kang, Young Namgoong, Suckchel Yang (Soongsil University, Korea), Sungsoo Choi (KERI, Korea), Yoan Shin (Soongsil University, Korea)	1458
5. Analysis of Energy Efficiency for Low Power Transmission in WLAN with MIMO-OFDM and Block Ack Mechanism	
Hoseok Choi, Sinchong Park (ICU, Korea)	1462

Session 8B: Mobile Communications (VIII)

1. A New Efficient BS Scheduler and Scheduling Algorithm in WiBro Systems	
Juhee Kim, Eunkyung Kim, Kyung Soo Kim (ETRI, Korea)	1467
2. Priority-based Call Admission Control of Multiclasses in Mobile Networks	
Nguyen Cao Phuong (PTIT, Viet Nam), Sang-Ho Lee, Jung-Mo Moon (ETRI, Korea), Tran Hong Quan (PTIT, Viet Nam)	1471
3. Efficient Fisheye State Routing Protocol using Virtual Grid in High-Density Ad-Hoc Networks	
Ting-Hung Chiu, Shyh-In Hwang (Yuan Ze University, Taiwan)	1475
4. Design, Development and Deployment of a Mobile E-Commerce Application for Rural South Africa – A Case Study	
B Chipangura (University of Fort Hare, South Africa), A Terzoli (Rhodes University, South Africa), H Muyingi, G.S.V.R.Krishna Rao (University of Fort Hare, South Africa)	1479
5. Flow-based Forwarding Scheme and Performance Analysis in Mobile IPv6 Networks	
Doan Huy Cuong, Jun Kyun Choi (ICU, Korea), Dipnarayan Guha (Nanyang Technological University, Singapore)	1485

Session 8C: Multimedia and Internet Systems and Services (VIII)

1. Implementation of a Real-time 3D Positioning Sound Synthesis Algorithm for a Handheld Device	
Giwoo Park, Pinaki S. Chanda, Tae Ik Kang (LG Electronics, Korea)	1493

2. Design and Implementation of Martini based Layer 2 VPN	
Suncheul Kim, HoYong Ryu (ETRI, Korea), Jaehyung Park (Chonnam National University, Korea), TaeIl Kim (ETRI, Korea)	1497
3. An Efficient Low Complexity Encoder for MPEG Advanced Audio Coding	
Xiaopeng Hu, Guiming He, Xiaoping Zhou (Wuhan University, China)	1501
4. Error Resilient MPEG-2 Video Coding Schemes Based on Three Layer Error Control Coding	
Changseok Bae, Jeunwoo Lee (ETRI, Korea), Vera Chung (University of Sydney, Australia)	1506
5. Improved Matching Algorithm for Services described by OWL-S	
Moonyoung Chung (ETRI, Korea), Hyun Namgoong (UST, Korea), Kyung-Il Kim, Seungwoo Jung, HyeonSung Cho (ETRI, Korea)	1510

Session 8D: Digital Home Technology (I)

1. Implementation of Initial Provisioning Function for Home Gateway Based on Open Service Gateway Initiative Platform	
SangOk Lee, HoJin Park (ETRI, Korea)	1517
2. A Personal Context-aware Universal Remote Controller for a Smart Home Environment	
Youngjae Kim, Dongman Lee (ICU, Korea)	1521
3. A Dynamic QoS Algorithm for Wireless AV Home Networks	
Jianlin Guo, Jinyun Zhang, William Chen (Mitsubishi Electric Research Laboratories, USA)	1526
4. A Media Distribution System supporting Priority-based QoS in a Home Network	
Sung-Gi Choi, Dong-Oh Kang, Jeun-Woo Lee (ETRI, Korea)	1532
5. Asynchronous Data Transfer on Wireless 1394 System	
Seong Hee Park, Seong Hee Lee, Sang Sung Choi (ETRI, Korea)	1537

Session 8E: Information Security Technology (VIII)

1. A Developing of Signature-based Network Security Tester for NGSS	
Younseo Jeong (ETRI, Korea), Junsang Jeon (Hannam University, Korea), Jongho Ryu, Dongil Seo (ETRI, Korea)	1543
2. A Computationally Secure Quantum Oblivious Transfer Scheme	
Xin Lu (Graduate School of Chinese Academy of Sciences, China), Zhi Ma (Information Engineering University, China), Deng-Guo Feng (State Information Center, China)	1547

3. Implementation of 10Giga VPN Accelerator Board	
Ki Hyun Kim, Jang-Hee Yoo, Kyo Il Chung (ETRI, Korea)	1552
4. A Simple Response Packet Confirmation Method for DRDoS Detection	
Hiroshi Tsunoda, Yoshiaki Nemoto (Tohoku University, Japan), Kohei Ohta (Cyber Solutions Inc., Japan), Atsunori Yamamoto (NTT Data Corporation, Japan)	1557
5. Denial-of-Service(DoS) Detection through Practical Entropy Estimation on Hierarchical Sensor Networks	
Mihui Kim, Inshil Doh, Kijoon Chae (Ewha Womans University, Korea)	1562

Session 8F: IT Service Technology (III)

1. A Service Template Authoring Environment for URC Service Composition	
Sangseung Kang, Joochan Sohn (ETRI, Korea)	1569
2. A New Method for Ontology Merging based on Concept using WordNet	
Miyoung Cho (Chosun University, Korea), Hanil Kim (Cheju University, Korea), Pankoo Kim (Chosun University, Korea)	1573
3. Palmprint Matching using Line Features	
Fang Li, Maylor K. H. Leung, Xiaozhou Yu (Nanyang Technological University, Singapore)	1577
4. Comparisons analysis of Security Vulnerabilities for Security Enforcement in IPv4/IPv6	
Hayoung Oh, Kijoon Chae (Ewha Womans University, Korea), HyoChan Bang, JungChan Na (ETRI, Korea)	1583
5. Desktop Migration System Based on Dynamic Linking of Application Specific Libraries	
Taein Hwang, Hojin Park (ETRI, Korea), Jin Wook Chung (Sungkyunkwan University, Korea)	1586

Session 8G: Digital Broadcasting Technology (I)

1. Authorization Refreshment Management Using ARL in DTV Broadcasting	
Han-Seung Koo, O-Hyung Kwon, Soo-In Lee (ETRI, Korea), Sung-Woong Ra (Chungnam National University, Korea)	1591
2. Single Frequency Network Design of DVB-H (Digital Video Broadcasting –Handheld) System	
Joo Chan Kim, Jin Young Kim (Kwangwoon University, Korea)	1595
3. The Effects of Human Hands on the Radiation Characteristics of Offset-fed Slot Antenna Embedded at the Back of Display of Notebook Computers for the Reception of Digital Terrestrial TV Broadcasting	
Muhammad Sajjadur Rahim, Tadahiko Maeda (Ritsumeikan University, Japan)	1599

4. A Path Control Architecture for Receiving Various Multimedia Contents	
Seong Yong Lim, Joo Myoung Seok, Han Kyu Lee (ETRI, Korea)	1604
5. Extended DMB BWS for a User-Friendly Mobile Data Service	
Heejeong Kim, Sora Park, Bongho Lee, Chunghyun Ann, YoungSung Son (ETRI, Korea)	1608

Session 8H: Poster Session (II)

1. A Novel QAM Joint Frequency-Phase Carrier Recovery Method	
Qijia Liu, Zhixing Yang, Jian Song, Changyong Pan (Tsinghua University, China)	1617
2. Simple Enhanced Overload Control Mechanism for Digital Exchange System	
Bong Uk Bin, Kyu Chul Lee, Jong Hyup Lee (Inje University, Korea)	1622
3. Design of Traffic Conditioner using Marking Algorithm on DiffServ-over-MPLS	
Sanghyun Park, Jinwoo Lee (Konkuk University, Korea), Jintae Kim (Fivetek. Co., LTD., Korea), Inkap Park (Konkuk University, Korea)	1627
4. Extended Service Registry for Distributed Computing Support in OSGi Architecture	
Kyuchang Kang, Jeunwoo Lee (ETRI, Korea), Hoon Choi (Chungnam National University, Korea)	1631
5. Challenges and Barriers in Implementing E-government: Investigation on NEIS of Korea	
Yong Soon Kim (KERIS, Korea)	1635
6. A Log-based Flash Translation Layer for Large NAND flash memory	
Soo-Young Kim, Sung-In Jung (ETRI, Korea)	1641
7. A Design and Implementation of ASIC for High-quality VoIP Terminal over Wireless LAN	
Do Young Kim (ETRI, Korea), Jong Won Park (CNU, Korea)	1645
8. An Application Level Gateway for Traversal of SIP Transactions through NATs	
Jae Cheon Han, Wook Hyun, Sun Ok Park, Il Jin Lee, Mi Young Huh, Shin Gak Kang (ETRI, Korea)	1649
9. Transmission Energy Efficiency in MIMO-OFDM based WLAN with HCCA Channel Access Scheme	
Seungbeom Lee, Sin-Chong Park (ICU, Korea)	1653
10. Baseball-shaped Circular Microstrip Antennas for Miniaturization	
Mi-ra Ryu (Konkuk University, Korea), Jong-Myung Woo (CNU, Korea), Jung Hur (Konkuk University, Korea)	1657
11. IPv6 Neighbor Discovery Protocol for Common Prefix Allocation in IEEE 802.16	
Hongseok Jeon, Junghoon Jee (ETRI, Korea)	1661
12. Key Factors for E-Commerce Business Success	
Jaekyung Choi, Jeongsuk Park, Jeehyung Lee, Kyungsuk Ryu (ETRI, Korea)	1664

13. The Design and Implementation of MAC Security in EPON	
Kyeong-Soo Han, Kwang-Ok Kim, Tae Whan Yoo, Yul Kwon (ETRI, Korea)	1673
14. An Improvement of Channel Efficiency for IEEE 802.15.3 High Rate WPAN	
Ji Eun Kim, Young Ae Jeon, Sangjae Lee, Sang Sung Choi (ETRI, Korea)	1677
15. Critical Design of the Ka-Band On-board Switching Transponder for Communication, Oceanographic, and Meteorological Satellite (COMS)	
Yong Min Lee, Seong Pal Lee (ETRI, Korea)	1681
16. Consideration of Efficient Nearest Node Discovering Mechanisms for Key Infection	
Jin-Bum Hwang, Young-Sik Hwang, Jong-Wook Han (ETRI, Korea)	1686
17. A Study for Providing Personal Contents using Open API Platform	
Hyun-Woo Oh, Kee-Seong Cho (ETRI, Korea)	1690
18. Efficient VLSI Implementation of the List Sphere Decoder with Real-value Based Tree Searching Method	
SangHo Seo, SinChong Park (ICU, Korea)	1694
19. A Study on User Data Management for SIP-based IMPP Services	
IlJin Lee, Wook Hyun, ShinGak Kang (ETRI, Korea)	1698
20. Design and Performance Analysis of HomePNA 2.0 Transceiver Chip Circuit	
Jong Won Kim, Jae Doo Huh (ETRI, Korea), Dae Young Kim (Chungnam National University, Korea)	1702
21. Design of SPI module in Large-Scale Network	
Seungyong Yoon, Jintae Oh, Jongsoo Jang (ETRI, Korea)	1706
22. A Flexible Control Strategy on Workflow Modeling and Enacting	
Jiantao Zhou, Xinming Ye (Inner Mongolia University, China)	1712
23. Korean-English Named Entity Alignment for Machine Translation of Digital TV Closed Caption	
Sanghwa Yuh (Kyungin Women's College, Korea), Jungyun Seo (Sogang University, Korea)	1717
24. Key Distribution Scheme Based on Two Cryptosystems for Hierarchical Access Control	
Bing Hu, Wu Ye, Sui-Li Feng (South China University of Technology, China), Xiao-Liang Wang (JiNan University, China), Xing Xie (GuangDong Information Center, China)	1723
25. Paging Scheme for High-speed Portable Internet (HPI) System	
Hyun Suk Roh, Sang-ho Lee (ETRI, Korea)	1729
26. Secure Discovery Method of Devices for a Home Network Middleware	
Do-Woo Kim, Geon-Woo Kim, Jun-Ho Lee, Jong-Wook Han (ETRI, Korea)	1733
27. Performance Evaluation of Software Streaming Server Architecture for Massive Users	
Sungjoo Kang, Kyong I Ku, Jeong Min Shim, Sung Jin Hur, Sang Hyun Ju, Wan Choi (ETRI, Korea)	1736

28. Conversation Preference Profile for Mobile Web Service	
Kangchan Lee, Wonsuk Lee, Jonghong Jeon, Seungyun Lee (ETRI, Korea), Jonghun Park (Seoul National University, Korea)	1742
29. Recovery Policies on a Web Services-based Business Process for Minimizing Human Intervention	
Jinyoung Moon, Rockwon Kim, Yeonjun Kim, Doha Lee, Hyeonsung Cho (ETRI, Korea)	1745
30. Periodic Medium Reservation Timer Mechanism for VoIP in IEEE 802.11 Wireless LAN	
Dae Ho Kim, Ki Jong Koo, Do Young Kim (ETRI, Korea)	1747
31. A Study on Heuristic Algorithms to construct the Local Loop Connection	
Jeongtae Kim, Soyoung Park, Tchanghee Hyun (ETRI, Korea)	1751
32. A WDM-Ethernet hybrid Passive Optical Network Architecture	
Jeong-Ju Yoo, Hyun-Ho Yun, Tae-Yeon Kim, Kang-Bog Lee, Mahn-Yong Park, Byoung-Whi Kim, Bong-Tae Kim (ETRI, Korea)	1754
33. Storage structure and management skills for RDF Schema versioning in RDB environment	
ByungGon Kim (Bucheon College, Korea), YounHee Kim, Haechull Lim (Hongik University, Korea) ...	1758

Session 9A: CDMA & Wireless Communications (IX)

1. Spectral Correlation Based Signal Detection Method for Spectrum Sensing in IEEE 802.22 WRAN Systems	
Ning Han, SungHwan Shon, Jae Hak Chung, Jae Moun Kim (Inha University, Korea)	1765
2. A Mixed-Radix 4-2 Butterfly with Simple Bit Reversing for Ordering the Output Sequences	
Young-jin Moon, Young-il Kim (ETRI, Korea)	1771
3. Asynchronous Uplink MC-CDMA with Multiuser Detection and Frequency Offset	
Won Mee Jang, Moon Woo Lee (University of Nebraska, USA)	1775
4. General Expression for the Error Probability of Arbitrary Two-Dimensional Signaling with I/Q Amplitude and Phase Unbalances	
Jaeyoon Lee, Dongweon Yoon, In Chul Im (Hanyang University, Korea)	1781
5. Novel Techniques of a List Sphere Decoder for High Throughput	
Jin Lee, Sin-Chong Park (ICU, Korea)	1785

Session 9B: Mobile Communications (IX)

1. *A Handover Framework for Seamless Service Support between Wired and Wireless Networks*
Ok Sik Yang (ICU, Korea), Seong Gon Choi (CBNU, Korea), Jun Kyun Choi (ICU, Korea), Jung Soo Park,
Hyoung Jun Kim (ETRI, Korea) 1791
2. *Communication Technologies for Collaborative Sensing and Control in Vehicular Ad-Hoc Networks*
Evtim Peytchev, Taha Osman, David Al-Dabass, Michael Thomas, Shi Zhi (Nottingham Trent University,
United Kingdom) 1797
3. *Considerations of Multiple Network Interface for a Mobile node*
Yong-Geun Hong, Jung-Soo Park, Hyoung-Jun Kim (ETRI, Korea) 1800
4. *The Framework for Mobility and Multihoming Using Overlay Network*
Taewan You, Seungyun Lee (ETRI, Korea) 1803
5. *A New Backoff Scheme of IEEE 802.11 Wireless Local Area Networks*
Il-Young Moon (Korea University of Technology and Education, Korea), Hwi-Jin Ye, Sung-Joon Cho
(Graduate School of Hankuk Aviation University, Korea) 1807

Session 9C: Multimedia and Internet Systems and Services (IX)

1. *The Design of the Ontology Retrieval System on the Web*
Myunggwon Hwang, Hyunjang Kong, Pankoo Kim (Chosun University, Korea) 1815
2. *PEAQ-based Psychoacoustic Model for Perceptual Audio Coder*
Xiaopeng Hu, Guiming He, Xiaoping Zhou (Wuhan University, China) 1819
3. *Gesture Analysis for Human-Robot Interaction*
Kye Kyung Kim, Keun Chang Kwak, Su Young Chi (ETRI, Korea) 1824
4. *RLS Algorithm Based Sub-Band Decomposition Low Memory Multimedia Applications*
Suprava Patnaik, Yogananda Patnaik, Anamika Upadhyaya (National Institute of Technology, India) 1828
5. *Packet Control Mechanism for Seamless Multimedia Streaming Service in Wireless Network*
Hyung Su Lee, Hee Young Youn (Sungkyunkwan University, Korea), Hye Dong Jung (KETI, Korea) 1833

Session 9D: Digital Home Technology (II)

1. *A Scheme Using OPES for Real-Time Translation Services in Digital Home Networks Based on Delivery Management Systems*
Il-Woo Lee, Ho-Jin Park, Kwang-Roh Park (ETRI, Korea), YOUNGHWAN CHOI, Sang-Ha Kim (Chungnam
National University, Korea) 1841

2. Augmented Interface Table based on Fingertip Recognition for Embedded Devices	
Sung-Ho Ahn, Ji-Yong Kim, Ji-Young Kwak (ETRI, Korea), Jee In Kim, Doo Hyun Kim (Konkuk University, Korea)	1845
3. Integrate LonWorks and UPnP devices by OSGi gateway and Universal Remote Console	
Yu-Hsiang Sheng, Wen-Wei Lin, Chia-Shou Tu, Kuen-Ming Lee (Industrial Technology Research Institute, Taiwan)	1848
4. Context-Aware based Mobile Service for Ubiquitous Home	
Hyunjeong Lee, Jongwon Kim, Jaedoo Huh (ETRI, Korea)	1851
5. The DLNA Proxy System Architecture for Sharing In-Home Media Contents via Internet	
Yeon-Joo Oh, Hoon-Ki Lee, Jung-Tae Kim, Eui-Hyun Paik, Kwang-Roh Park (ETRI, Korea)	1855

Session 9E: ASP, WAS, P2P, CDN, and XML Technologies

1. Performance evaluation of Open Source Native XML databases – A Case Study	
Ntima Mabanza, Jim Chadwick, G.S.V.R.Krishna Rao (University of Fort Hare, South Africa)	1861
2. P2MVOD: Peer-to-Peer Mobile Video On-Demand	
Katsuhiko Sato (Japan Radio Co., Ltd., Japan), Michiaki Katsumoto (National Institute of Information and Communications Technology, Japan), Tetsuya Miki (The University of Electro-Communications, Japan) ...	1866
3. The Index Organizations for RDF and RDF Schema	
YounHee Kim (Hong-Ik University, Korea), ByungGon Kim (Bucheon College, Korea), HaeChull Lim (Hong- Ik University, Korea)	1871
4. An Overlay Resource Monitor System	
Chih-Chen Wang, Yung-Mu Chen, Cheng-Hao Weng, Tein-Yaw Chung (Yuan Ze University, Taiwan) ...	1875
5. Contents Conversion Service Network	
Heang-Suk Oh, Teak-Yong Nam (ETRI, Korea)	1880

Session 9F: IT Service Technology (IV)

1. Design and Implementation of Session Management for n-to-n Multicast	
Okjo Jung, Juyoung Park, ShinGak Kang (ETRI, Korea)	1887
2. Modeling of Heart Phantom using the Multidipole Current Source	
Dal-Hwan Yoon, Sun Hyo Lee, Dong Ju Bae, Ho Kyun Kim (Semyung University, Korea)	1891
3. 3D Sound Localization Cues using HRTF Database Built with Dummy Head	
Alexander Ovcharenko, Ui-Pil Chong (University of Ulsan, Korea)	1895

4. *Design and Implementation of Real-Time Security Guard Robot using CDMA Networking*
 Je-Goon Ryu (Korea Polytechnic University, Korea), Hyeon-Min Shim, Se-Kee Kil (Korea Polytechnic University, Korea), Eung-Hyuk Lee (Korea Polytechnic University, Korea),
 Heung-Ho Choi (Inje University, Korea), Seung-Hong Hong (Inha University, Korea) 1901
5. *A study on the Service Process Generation System for Intelligent Robot*
 Cheonshu Park, Joochan Sohn (ETRI, Korea) 1907

Session 9G: Digital Broadcasting Technology (II)

1. *High Speed MPEG-2 TS Scrambling System with DVB-Common Scrambling Algorithm*
 Joon-Young Jung, O-Hyung Kwon, Soo-In Lee (ETRI, Korea) 1913
2. *Performance Enhancement of a DBS receiver using Hybrid Approaches in a Real-Time Environment*
 Sung-Hoon Kim (ETRI, Korea), Yeong Rak Seong, Kyeong Hoon Jung, Dong Wook Kang, Ki-Doo Kim (Kookmin University, Korea) 1917
3. *Nonlinear Filtering for Rejection ISI in FSK Modulation*
 Mohammad Reza Tarihi, Asghar Taheri (Malek Ashtar Univerisity of Technology, Iran), Kamal Mohamed-Pour (K. N. Toosi Univerisity of Technology, Iran) 1921
4. *The Interactive Contents Authoring System for Terrestrial Digital Multimedia Broadcasting*
 Won-Sik Cheong, Jihun Cha, YeSun Joung, Kyuheon Kim (ETRI, Korea) 1926
5. *An Efficient Method of Personalized Broadcasting on the Interactive Broadcast Network*
 Joo-Myoung Seok, Seong Yong Lim, Heekyung Lee, Han-Kyu Lee (ETRI, Korea) 1931

Session 10A: CDMA & Wireless Communications (X)

1. *Low Complexity MMSE-QRD-based ML Decoder for Quasi-Orthogonal STBC scheme in MIMO Wireless Communications Systems with Four-Transmit Antennas*
 Van-Su Pham, Minh-Tuan Le, Linh Mai, Giwan Yoon (ICU, Korea) 1937
2. *Low-Complexity Generalized Layered Space-Time MIMO Detection*
 Yuhei Nagao, Masayuki Kurosaki, Hiroshi Ochi (Kyushu Institute of Technology, Japan) 1940
3. *The Optimization of the Collision Resolution Algorithm for Broadband Wireless Access Network*
 Sung-Min Oh, Jae-Hyun Kim (Ajou University, Korea) 1944

4. *A Robustness Analysis of a Practical Contention Resolution Algorithm under Misbehaved users in Wireless Communication Systems*
Chalotorn Chanasong, Warakorn Srichavengsup, Lunchakorn Wuttisittikulkij (Chulalongkorn University, Thailand) 1949
5. *A Optimal CF-Poll Piggyback Scheme in IEEE 802.11e HCCA*
Hyun-Jin Lee, Jae-Hyun Kim (Ajou University, Korea) 1954

Session 10B: Mobile Communications (X)

1. *Keep-Alive Algorithm based Periodic Ranging Code Group for detecting abnormal SS in WiBro System*
Sook-Jin Lee (ETRI, Korea), Whan Woo Kim (Chung-Nam National University, Korea) 1963
2. *Energy-based Route Discovery Mechanism in Mobile Ad Hoc Networks*
Jirasak Kanjanarot, Kowit Sitthi, Chaiyachet Saivichit (Chulalongkorn University, Thailand) 1967
3. *Intermediary based Architecture for Mobile Web Services*
Wonsuk Lee, Kangchan Lee, Seungyun Lee (ETRI, Korea) 1973
4. *The Applicability of SCTP to Mobile Ad Hoc Networks*
Dongkyun Kim, Jeomki Song, Jounghsik Kim, Hongseok Yoo (Kyungpook National University, Korea), Jungsoo Park (ETRI, Korea), Juan-Carlos Cano (Polytechnic University of Valencia, Spain) 1979
5. *Route Optimization Using RIPng Protocol in Nested Network Mobility*
Sung Hei Kim, Yoon Young Ahn (ETRI, Korea), Sang Ha Kim (ChungNam National University, Korea), Tae Il Kim (ETRI, Korea) 1985

Session 10C: IPv6 Technology (I)

1. *An Empirical Analysis of IPv6 Transition Mechanisms*
Myung-Ki Shin, Hyoung-Jun Kim (ETRI, Korea), Darrin Santay, Doug Montgomery (NIST, USA) 1991
2. *Network Side Fast handover Support in Mobile IPv6*
HeeYoung Jung, HongSeok Jeon (ETRI, Korea) 1997
3. *Design, Implementation and Evaluation of Source-Specific Multicast System over IPv6 Networks*
Sangjin Jeong, Myung-Ki Shin, Hyoung-Jun Kim (ETRI, Korea) 2000
4. *Protection Algorithm against Security Holes of IPv6 Routing Header*
JaeDeok Lim, YoungKi Kim (ETRI, Korea) 2004

- 5. An Efficient Mechanism for Multicast Deployment in IPv6**
 Min-kyo In, Seung-yun Lee, In-dong Jang, Tae-wan You (ETRI, Korea) 2008

Session 10D: Communication Network Topology & Planning (I)

- 1. Comparison of Cost for Different Coverage Scenarios between Copper and Fiber Access Networks**
 Michael Jensen, Rasmus Hjorth Nielsen, Ole Brun Madsen (Aalborg University, Denmark) 2015
- 2. Internet Topology Modeling which Reflects Hierarchical and Dynamic Characteristic of Internet**
 Ju-hang Sohn, Jung-ryul Kim, Joo-seong Park, Hyo-jun Lee, Min-taig Kim (ETRI, Korea) 2019
- 3. Demonopolization of Russian Long Distance Communication Market using SS 7 Network**
 Oleg Semanov (North-West Telecom, Russian Federation), Vladislav Pyattaev (FSUE LONIIS, Russian Federation), Vitaly Danilov (St. Petersburg State University of Telecommunications, Russian Federation) 2025
- 4. Content-based Pattern Matching for Classification of Network Application**
 Kwangjin Choi, Jun-kyun Choi (ICU, Korea), Sangyong Ha (NCA, Korea), Se Yun Ban (ICU, Korea) .. 2027
- 5. Intrinsic Fitness and Preferential Attachment in Scale-free Networks**
 Hongbo Liu, Jiaxin Wang (Tsinghua University, China) 2030

Session 10E: GRID, Distributed Computing Technologies & Services (I)

- 1. Work Packet Manager: Exploiting Heterogeneity in Cluster Computing**
 KyuHo Lee, Jongsu Yi, JunSeong Kim (Chung-Ang University, Korea) 2035
- 2. Load Balancing of OLTP on Heterogeneous Database Cluster**
 Weihua Gong, Yuanzhen Wang (Huazhong University of Science and Technology, China) 2040
- 3. A Method for Representing and Transporting CIM Operations using Binary XML in the WBEM Architecture**
 Jong-Geun Park, Chang-Won Ahn, Hee-Nam Cho, Il-Soo Byun, Frederic Desmons, Seong-Woon Kim (ETRI, Korea) 2046
- 4. Implicit Information Load Sharing Policy for Grid Computing Environment**
 Natthakrit Sanguandikul, Natawut Nupairoj (Chulalongkorn University, Thailand) 2050
- 5. Lifetime Maximization by Cross-Layer Interaction in Wireless Sensor Networks**
 In-Yeup Kong (Pusan National University, Korea), Won-Joo Hwang (Inje University, Korea) 2055

Session 10F: Portable Internet and Internet Telephony

1. *Design and Development of the Intelligent SSW and SIP Application Server System*
Kwihoon Kim, Hyun-Woo Lee, Won Ryu (ETRI, Korea) 2063
2. *Policy Analysis and Studies on a Model for Determining an Optimal VoIP Access Charge*
Sung Uk Park (KISTI, Korea) 2067
3. *Application Method of QoS, IPv6, Security in Wibro*
Kyu Ouk Lee, Jin Ho Hahm, Young Sun Kim (ETRI, Korea) 2071
4. *Complexity Analysis of a Dual Round-Robin based iSLIP (DiSLIP) Scheduling Scheme*
Jin Seek Choi (Hanyang University, Korea), Mijeong Yang, Tae Il Kim (ETRI, Korea) 2075
5. *A Emergency Call Service Mechanism on SIP Internet Telephony System*
Sun Ok Park, Jae Cheon Han, Wook Hyun, Mi-Young Huh, Shin Gak Kang (ETRI, Korea) 2080

Session 11A: CDMA & Wireless Communications (XI)

1. *Impact of the Antenna Shuffling in V-BLAST System using NAK for H-ARQ in Correlated Fading Channels*
Bonghoe Kim (LG Electronics, Korea), Seung-Hoon Hwang (Dongguk University, Korea) 2087
2. *Finite Element based Beam Propagation Method for 3D Wave Propagation in Troposphere*
Kamran Arshad, Ferdinand Katsriku, Aboubaker Lasebae (Middlesex University, United Kingdom) 2090
3. *A MIMO-OFDM System with Simple Bit Allocation and Spatial Resource Grouping Based Beamforming*
Daejin Park, Suckchel Yang, Yoan Shin (Soongsil University, Korea) 2095
4. *Compensation of the OFDM Non-linear Distortions by the Inverse Model Method*
Rafik Zayani, Rim Guedria, Ridha Bouallegue (ISI, Tunisia) 2099
5. *Iteration Based Performance Evaluation of LDPC coded MIMO-OFDM*
HyoungSoon Kim, SinChong Park (ICU, Korea) 2103

Session 11B: Network Management, Operation and Maintenance

1. *Review on QoS issues in IEEE 802.11 W-LAN*
Jaekyung Choi, Jeongsuk Park, Jeehyung Lee, Kyungsuk Ryu (ETRI, Korea) 2109
2. *The Study on SLA Metrics and System Architecture for IP TV*
Seong Hwan Kim, Gil Haeng Lee (ETRI, Korea) 2114

3. Adaptive One Increased-Order Deadbeat Congestion Control Algorithm for ABR Traffic in ATM Networks	
Thang Viet Nguyen, Takehiro Mori, Yoshihiro Mori (Kyoto Institute of Technology, Japan)	2118
4. The Design of Dynamic Authorization Model for User centric service in Mobile Environment	
Byunggil Lee, Howon Kim, Kyoil Chung (ETRI, Korea)	2124
5. Constructing the Channelized Interface on the Next-Generation SONET/SDH System	
Seung-Woo Hong, Byung-Ho Yae (ETRI, Korea)	2128

Session 11C: IPv6 Technology (II)

1. Implementation Issues for IPv6 Software Forwarding in Routing System	
Hyun Joo Kang, Yoon Young Ahn, Sung Hei Kim, Byung Ho Yae (ETRI, Korea)	2135
2. On IPv6 Traceback	
Syed Obaid Amin, Choong Seon Hong (Kyung Hee University, Korea)	2139
3. IPv6 Multihoming for NGN	
Hyoung-Jun Kim, Yong-Geun Hong (ETRI, Korea), Sang-Ha Kim (Chungnam National University, Korea)	2144
4. A Scalable Global IPv6 Anycast Routing Support Mechanism	
Jong Min Lee, Dipnarayan Guha, Jun Kyun Choi (ICU, Korea), Jung Soo Park, Hyoung Jun Kim (ETRI, Korea)	2148
5. IPv4/IPv6 Forwarding Control Architecture in Distributed Router	
Yoo-Hwa Kang, Tae-Il Kim (ETRI, Korea)	2152

Session 11D: Communication Network Topology & Planning (II)

1. Source-based Multiple Gateway Selection Routing Protocol in Ad-hoc Networks	
Byung-jin Lee, Soon-Gyu Jeong, Sang-jo Yoo (Inha University, Korea)	2159
2. Investigation of Cost Reductions through Synergy Effects when Deploying Commercial WANS	
Rasmus Hjorth Nielsen, Michael Jensen, Ole Brun Madsen (Aalborg University, Denmark)	2164
3. Performance Analysis of Cooperative Communications Protocol using Sum-Product Algorithm for Wireless Relay Networks	
Ho Van Khuong, Hyung-Yun Kong (University of Ulsan, Korea)	2168
4. Five Novel Selection Policies for N2R Network Structures	
Jens Myrup Pedersen, Tahir M. Riaz, Ole Brun Madsen (Aalborg University, Denmark)	2174
5. The System Integration of DRM and Fingerprinting	
Jung-Soo Lee, Ki-Song Yoon (ETRI, Korea)	2180

Session 11E: GRID, Distributed Computing Technologies & Services (II)

1. A LanLinux-Based Grid System for Bioinformatics Applications

Tae-Kyung Kim, Sang-Keun Oh, Wan-Sup Cho (Chungbuk National University, Korea) 2187

2. Modeling and Verification of Some Communication Protocols

Kamrul Hasan Talukder, Koichi Harada (Hiroshima University, Japan) 2193

3. Effective Semantic Web Services Discovery using Usability

Hyun Namgoong (UST, Korea), Moonyoung Chung, Kyung-il Kim (ETRI, Korea),
HyeonSung Cho, Yunku Chung (UST, Korea) 2199

4. Block-Based Grid Caching for Grid Datafarm

Teerayut Hiruntaraporn, Natawut Nupairoj (Chulalongkorn University, Thailand) 2204

5. Design and Implementation of the Script-based Service Deployment Solution

Wonjae Lee, Yuhyeon Bak, Sangmin Woo, Changsoo Kim, Okgi Min, Hak-Young Kim (ETRI, Korea) .. 2208

Session 11F: E-Commerce and M-Commerce

1. Design and Implementation of RBAC Framework for Privacy on NEIS

Yong Soon Kim (KERIS, Korea), Eui Kyeong Hong (University of Seoul City, Korea) 2213

2. Development of a localized E-Commerce Platform for Music using Indigenous Knowledge -A South African Experience

Gary O.G Ndlovu, Alfredo Terzoli, Alvin Petersen, Hippolyte Muyingi, G.S.V.R.Krishna Rao (University of Fort Hare, South Africa) 2219

3. A Software Architecture to Support Digital Document Interchange for the [Chilean Government

Sergio F. Ochoa, Pedro O. Rossel, María Cecilia Bastarrica (University of Chile, Chile) 2223

4. From Detecting to Recognizing Color Codes

Jachwan Park (Sangmyung University, Korea), Woosung Kim (Hoseo University, Korea), Hyeon-Joong Yoo,
Youngbum Jang (Sangmyung University, Korea) 2228

5. Smart Card initiative for South African E-Governance – A Study

Peter T. Nkomo (University of Fort Hare, South Africa), Alfredo Terzoli (Rhodes University, South Africa),
Hippolyte Muyingi, G.S.V.R.Krishna Rao (University of Fort Hare, South Africa) 2231

Author Index

Physical Layer Analysis of Emerging IEEE 802.11n WLAN Standard

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Abstract - In January 2004 IEEE announced that it had formed a new 802.11 Task Group N (TGN) to develop a new amendment to the 802.11 standard for wireless local-area networks that will be known as IEEE 802.11n standard. The real data throughput will be at least 100 Mbps, with possibility of even higher raw data rate at the physical layer (PHY), and should be up to 5 times faster than 802.11a or 802.11g, and perhaps 25 times faster than 802.11b in mandatory modes of operation. It is projected that 802.11n will also offer better operating distance and full compatibility with current WLANs. There are two competing proposals of the 802.11n standard, expected to be ratified: WWiSE and TGNsync. This paper on PHY compares new technical solutions of these two proposals believing that the best of these proposals will be incorporated in 802.11n standard. We also emphasize features and technical solutions on PHY that inevitably will be built in emerging 802.11n standard.

1. Introduction

Wireless local-area networks (WLAN) are evolving towards the development of broadband applications, including multimedia services in a way to compete with wired LAN systems. It is expected that rapid growth of mobile users will eventually demand the development of new applications with broadband access and bit rates higher than 54 Mbps, what is currently offered by IEEE 802.11a and g standards. Only 50-60% of that nominal bit rate is devoted to user traffic, due to the overhead imposed by physical-layer (PHY) frame header, preamble transmission and requirement that each sent frame must be acknowledged. Therefore, the aim of today's research effort is to provide high bandwidth WLAN communication system with similar performance, reliability and security compared to its wired counterpart. As WLAN technology matures, newer features and functionality will continue to be made available. Standardization organizations, like IEEE are providing continuous effort to meet new demands from users by introducing new standards as well as minimizing shortcomings of the previous standards [1, 7].

In January 2004 IEEE announced that it had formed a new 802.11 Task Group N (TGN) to develop a new amendment to the 802.11 standard for wireless local-area networks [6, 7, 8]. TGN's goal is to achieve 100 Mbps net throughput, after subtracting all the overhead for protocol management features like preambles, interframe spacing, and acknowledgments. There are two approaches to achieve 100 Mbps throughput: improve the efficiency of the MAC, increase the peak data rate well beyond 100 Mbps - or both. Between many partial and few complete proposals submitted for ratification to IEEE 802.11 TGN, support has coalesced around two main competing proposals, from groups named TGNsync and

WWiSE (World-Wide Spectrum Efficiency), where the third group named MIMOT had also highly ranked proposal [2, 3, 6]. The core of WWiSE group is composed of companies including Broadcom, Airgo networks, Conexant Systems, AT&T, HP, Texas Instruments, STMicroelectronics with Nokia and Motorola joined to the group later [2]. TGNsync group is backed by Atheros, Agere, Marvell, Qualcomm and Intel Corporation. However, quite a few manufacturers of electronic devices that might use 802.11 (Cisco, Nortel, Philips, Samsung, Sanyo, Sony, Panasonic, Mitsubishi, Hitachi...) have also become part of the effort, and they are disproportionately represented in TGNsync group [3]. The standardization process is expected to be completed by the end of 2006.

According to the vote support in IEEE TGN, TGNsync proposal will probably be the basis for the 802.11n specification, but some solutions trading will likely result in a WWiSE or even a few MIMOT features being incorporated. Thus, it is to be expected that final standard will have some resemblance to both of competing standards, and will likely choose features from each in order to bring new standard that will be known as IEEE 802.11n specification. As a result, this paper describes PHY of both of the main competing proposals, emphasizing elements that inevitably must be built in future standard. Since many new basic concepts are shared between the two proposals, our goal is to describe these basic concepts and predict what best features of every main proposal will be incorporated in new standard. Detail technical realization of some concepts will not be presented in this paper because proposals themselves may have slightly changed since the drafts upon which this paper was based were written. The main contribution of this paper is presentation of new concepts, features and technical solutions that will be, in our opinion implemented in emerging 802.11n standard.

This paper is organized as follows: section 2. outlines MIMO operation and transmission of single data stream across multiple antennas. In Section 3., we briefly describe operating channel structure of both proposals. Modulation types and data rates of two main proposals are pointed out in section 4. Section 5. describes different transmission modes. Finally, section 6. emphasizes enhancements in improving MAC efficiency that are incorporated inside proposals.

2. MIMO systems

New 802.11n standard builds upon previous 802.11 standards, especially 802.11a standard by adding MIMO (Multiple-Input/Multiple-Output) operation. So far, most of

802.11 devices had a single antenna, or even two antennas in a diversity configuration, but the basis of diversity is that the “best” antenna is selected. In diversity configurations, only a single antenna is used at any point. Although there may be two or more antennas, there is only one set of components to process the signal, or RF chain. The receiver has a single input chain, and the transmitter has a single output chain. The next step beyond diversity is to attach an RF chain to each antenna in the system. This is the basis of MIMO operation. Each RF chain is capable of simultaneous reception or transmission, which can dramatically improve throughput. Furthermore, simultaneous receiver processing has benefits in resolving multipath interference, and may improve the quality of the received signal far beyond simple diversity. Each RF chain and its corresponding antenna are responsible for transmitting a spatial stream. A single frame can be broken up and multiplexed across multiple spatial streams, which are reassembled at the receiver [1, 5]. MIMO operation will be built in new standard since it is reliable technology for boosting data rate through parallel transmission of multiple spatial streams proposed by both groups.

In most cases, an antenna will be used for each spatial stream what is defined as basis in both of proposals. However, there may be cases when the number of antennas is greater than the number of spatial streams. Thus, it is important to emphasize the difference between the number of transmit antennas and the number of spatial streams, where the number of spatial streams (will probably be equal to 1,2,3, or 4) must be less than or equal to the number of transmission antennas. Support for at least two spatial streams will probably be mandatory. If, for example, most APs wind up using three antennas while clients only use two, there is an “extra” transmit antenna, and the two spatial data streams need to be assigned to the three antennas. Transmitting a single spatial stream across multiple antennas will be used in some transmission modes of new 802.11n devices.

Space-time block coding (STCB) is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that transmitted data must traverse a potentially difficult environment with scattering, reflection, refraction and so on as well as be corrupted by thermal noise in the receiver means that some of the received copies of the data will be ‘better’ than others. Thus, STBC combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible [5]. When there are extra antennas, the WWiSE proposal mandates that a single spatial stream is transmitted on only 2 antennas using basic STBC rule also called Alamouti code [4, 2]. If the number of spatial streams is less than the number of transmit antennas, a TgnSync proposal defines usage of spatial steering matrix in order to assign bits to transmission antennas for some transmission modes. The unitary matrices are presented in TgnSync proposal for construction of spatial spreading antenna map enabling transmission of single spatial stream over 2, 3 or 4 antennas without usage of classical STBC codes [3]. Although unitary matrices of TgnSync proposal enables that each spatial stream maps equal energy

to each antenna, space-time block codes have low cost, wide flexibility, and no overhead. We give advantage to classical STCB coding with possibility of single spatial stream transmission over 2, 3, and 4 antennas with equal energy.

MIMO antenna configurations are often described with the shorthand “YxZ”, where Y and Z are integers, used to refer to the number of transmitter antennas and the number of receiver antennas. For example, both WWiSE and TgnSync require 2x2 operations, which have two transmit chains, two receive chains, and accordingly to that two spatial streams multiplexed across the radio link [1, 2, 3]. Thus 2x2 operation will probably be mandatory operation for every 802.11n device. Both proposals also have additional required and optional modes. Therefore, it is likely that most products that are based on the eventual 802.11n standard will support additional required modes and at least some of the optional modes. It is likely that the common hardware configuration will require operating in a two-transceiver mode on the client side to save cost and battery power, while access points (AP) will have more transceivers (antennas). Basic APs may have only two, while the most expensive enterprise-class APs will probably have three or four transceivers (RF chains, antennas). Configurations that will be mostly found on the market would use 2x2 (1x2), 2x3 (1x3), 2x4 (1x4) MIMO operation for its uplink communication (from mobile clients to AP), and 2x2 (2x1) 3x2 (3x1), 4x2 (4x1) MIMO operation on the downlink (from AP to mobile clients). The fact that more antennas are feasible at AP and fewer at mobile clients implies that asymmetric way of working will be built in new standard.

3. Channel structure

IEEE 802.11b,a,g standards currently use 20 MHz channels because that is the channel bandwidth allowed by all regulators worldwide. Doubling the channel bandwidth to 40 MHz doubles the theoretical information capacity of the channel. Also, 40 MHz channels are only supported in the 5 GHz band because it is not possible to squeeze multiple 40 MHz channels into the 2.4 GHz ISM band. Although promising for the future, some regulators do not currently allow 40MHz channel operation. Japan is the most notable exception. We are sure that support for 20 MHz channels will be mandatory for backward compatibility with older standards, but support for 40MHz channels will also be built in new 802.11n standard. Reasons for that perception lie in the fact that both proposals define usage of 20MHz and 40 MHz channels, and because usage of 40MHz channels redoubles peak bandwidth. Both proposals are slightly evolution of 802.11a, using MIMO technology. Thus, orthogonal frequency-division multiplexing (OFDM) used in 802.11a,g technologies is also basic channel coding and transport mechanism of two proposals and it will be built in new 802.11n standard.

WWiSE proposal uses both 20 MHz and 40 MHz channels, without defining usage of 40MHz channels as mandatory [2]. 40 MHz operation may be through a single 40 MHz channel, or through a 20 MHz channel pair in which both channels are used simultaneously for data transmission.

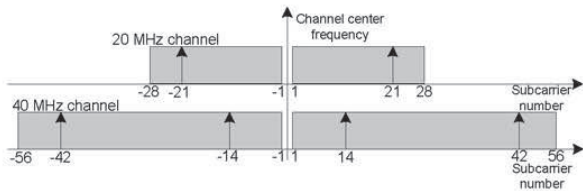


Fig. 1. 20MHz and 40 MHz Channel Structure of WWiSE Proposal

One channel is designated as the primary channel, and operates normally. The secondary channel is used only for channel aggregation (for “overflow” from the primary), and does not have stations associated on it. Although the first TGnSync proposal makes 40MHz channel support mandatory, harmonization between the two proposals has occurred imposing only optional usage of 40MHz channel band, what is originally defined in WWiSE proposal. Thus, TGnSync chipset would support work in 20 MHz channel band as mandatory operation while work in single, continues 40 MHz channel band will be optional. The TGnSync proposal also has MAC features that enable the use of networks with both 20 MHz and 40 MHz-capable stations. When stations have large amounts of data to transmit, it is possible to negotiate a temporary use of a wider channel before falling back to 20 MHz operation [1, 3]. In both proposals, 20 MHz and 40 MHz channels have subcarrier frequency spacing equal to 0.3125 MHz, just as in 802.11a standard. These frequency spacing are obtained by dividing 20 MHz channel with 64 and 40MHz channel with 128 possible subcarrier frequency slots. It is to be expected that new standard will impose the some subcarrier frequency spacing in both bands equal to 0.3125 MHz.

The 20MHz radio channel in WWiSE proposal uses 56 operational subcarriers, and 40 MHz channels, which are optional in WWiSE proposal uses 112 operational subcarriers (Figure 1). As in 802.11a OFDM, few subcarriers are set aside as pilots to monitor the performance of the radio link. Theoretically, fewer pilot carriers are needed in a MIMO system because the pilot carriers run through as many receiver chains. A 20 MHz 802.11a channel uses four pilot subcarriers. In the WWiSE proposal, a 20 MHz channel requires only 2 pilot carriers because each pilot is processed by 2 receiver chains, which has the same effect as 4 pilots processed by a single receiver chain. With fewer pilots, more subcarriers can be devoted to carrying data. 20 MHz WWiSE channels have 54 data subcarriers and 40 MHz channels with 4 pilots have exactly twice as many equal to 108 (Figure 1.). These data subcarriers provide separate pathways for sending the user information in parallel fashion based on OFDM technology also used in 802.11a,g standard.

In the first TGnSync proposal, 20 MHz channel was identical to an 802.11a channel structure requiring 52 operational subchannels with 4 pilots subchannels. But, convergence between group proposals results in TGnSync 20MHz channel structure proposal with equal number of operating subcarriers (56) like in WWiSE proposal. Two extra data subcarriers are added at the ends on each side from the center of the legacy (802.11a) 20 MHz channel, creating 20 MHz channel structure with 56 operational subcarriers

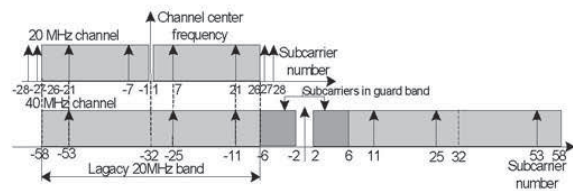


Fig. 2. 20MHz and 40 MHz Channel Structure of TGnSync Proposal

(Figure 2.). Only difference when compared to WWiSE proposal is the number of pilot subcarriers equal to 4, since TGnSync channel structure proposal was based on 802.11a channel structure (Table 1.). The 40 MHz channel proposed by TGnSync is a modification of the 20 MHz structure (Figure 2.). Two 20 MHz channels are bonded together, and the resulting spectral band uses 114 operational subchannels. The center frequencies of the old 20 MHz channels are located at ± 32 th subcarrier of the new 40MHz channel with the number of center null subcarriers equal to 3 (-1, 0, 1). The legacy channels (802.11g,a) apply a spectral mask from -6 to +6 and roll off the amplitude of transmissions at the end of the bands. With a single continuous 40MHz channel, however, there is no need to use a spectral mask, and the middle of the band can be used at full strength. To further boost throughput, one of the pilot carriers from the 20 MHz channel is removed, so a 40 MHz channel has 6 pilot carriers instead of 8 (Figure 2). Rather than simply double the throughput as in case of WWiSE proposal, a 40 MHz channel in TGnSync proposal with 108 data subcarriers provides throughput equal to 2.0769... (108/52) times higher than 20 MHz channel with 52 data subcarriers.

Spectral usage was the first major point of contention between the two groups, with main question of defining usage of 40MHz channels mandatory or not. If the usage of 40 MHz would be ratified as mandatory, it would lead to chipsets that are always capable of 40 MHz operation, adding extra cost and complexity, even though regulators may not allow them. Also mandatory usage of 40 MHz channels to improve the data rate before improving efficiency will be a waste of scarce unlicensed spectrum. Since both groups agreed upon usage of 20 MHz channel mode as mandatory and 40MHz channel mode as optional, we strongly believe that this channel mode usage will be incorporated in new 802.11n standard. In countries where 40 MHz channels are allowed, the extra speed would be welcome and 40 MHz channels will be used. Also, in areas where 40 MHz channels are disallowed, the reduction in extra costs which might be caused by optional 40MHz channel operation will be gladly accepted. Since WWiSE 20 MHz channel structure proposal has only 2 pilot subcarriers, the number of subcarriers dedicated to data transmission is slightly higher than in TGnSync proposal. But, quantitative analyses show that usage of only 2 pilots causes significant performance degradation what is not justified by the less than 4% data rate increase. Also, WWiSE proposal merely doubles throughput in their 40 MHz mode where TGnSync squeezes more than double (2.0769... times) of the capacity out in the 40MHz channel. For these reasons we believe that TGnSync 20 and 40MHz channel structure proposal with or without some

Table 1. Mandatory/Optional Cannel Parameters and Modulation Techniques of Both Proposals

TGnSync proposal (Draft details August 2005)							WWiSE proposal (Draft details August 2005)										
Chann-el band (MHz)	No. of possible special streams	Modulat-ion type	Coded bits/ Subcar.	Code rate	Modu-lat.op-tions	ABM Code rate	Mand.	Opt.	Mand.	Opt.	Chann-el band (MHz)	No. of possible special streams	Modulat-ion type	Coded bits/ Subcar.	Code rate	Modu-lat.op-tions	
							Number of special streams										
							1and2	1to4	only2	1to4							
20, 40	1,2,3,4	BPSK	1	1/2	2×4=8		Number of transmit antennas				40,20*	1*,2,3,4	BPSK	1	1/2	1×4=4	
20, 40	1,2,3,4	QPSK	2	1/2	2×4=8	1/2	2	1to4	2	1to4	40,20*	1*,2,3,4	BPSK	1	3/4	1×4=4	
20, 40	1,2,3,4	QPSK	2	3/4	2×4=8	3/4	Chennelisin bandwidth (MHz)				40,20*	1*,2,3,4	QPSK	2	1/2	1×4=4	
20, 40	1,2,3,4	16-QAM	4	1/2	2×4=8	1/2	20	40	20	40	40,20*	1*,2,3,4	QPSK	2	3/4	1×4=4	
20, 40	1,2,3,4	16-QAM	4	3/4	2×4=8	3/4	Number of occupied subcarriers				40,(20*)	1*,(2,3,4)	16-QAM	4	1/2	4+3=7	
20, 40	1,2,3,4	64-QAM	6	2/3	2×4=8		56	114	56	112	40,(20*)	1*,(2,3,4)	16-QAM	4	3/4	4+3=7	
20, 40	1,2,3,4	64-QAM	6	3/4	2×4=8	1/2,3/4	Number of data subcarriers				40,(20*)	1*,(2,3,4)	64-QAM	6	2/3	4+3=7	
20, 40	1,2,3,4	64-QAM	6	5/6	2×4=8		52	108	54	108	40,(20*)	1*,(2,3,4)	64-QAM	6	3/4	4+3=7	
20, 40	1,2,3,4	256-QAM	8			1/2,3/4	Number of pilot subcarriers				40,(20*)	1*,(2,3,4)	64-QAM	6	5/6	4+3=7	
Number of modulation options-basic (advanced mod)						64	94	4	6	2	4	Number of modulation options-basic(advanced)mode					49 (9*)
Guard interval (ns)							800	400	800	800	Guard interval (ns)						

changes will be incorporated in new standard.

On the other hand, ratification of 40MHz channel usage as optional, opens possibility that two types of 802.11n devices will be present on the market: devices that support operation in 20 MHz channel mode only, and devices that support operation in both channel modes (20/40). First one can reach peak data rates of 270Mbps (WWiSE) or 260/288.89 Mbps (TGnSync), for maximum parameters currently defined in every standard (4 special streams, 64-QAM with 6 coded bits per carrier and 3/4 code rate). We express our fear that different types of devices ratified by the same standard might cause confusion between average customers, appealing on manufacturers, vendors and regulatory bodies to simply and clearly define differences between various devices. We also worn about the fact that price gap between two types of devices might discourage costumers in purchasing 2 (20/40 MHz) mode devices in areas where 2 mode operation is allowed, declining benefits of more then double peak data rates that future 802.11n standard in 2 mode operation will probably offer.

4. MIMO modulation rates

There are 24 data rates defined by the WWiSE PHY proposal, with 49 different modulation options in mandatory and optional basic mode of working (Table 1.). Extra advanced optional working mode defines 9 additional modulation options with STBC coding (* in Table 1.) [2]. On the other hand, basic mandatory and optional modes of TGnSync PHY proposal define 32 different modulation and coding pairs what equals to 64 modulation options (Table 1.). Advance beamforming mode (ABM) of TGnSync offers 94 extra modulation options in mandatory and optional working modes [3]. Devices that will work accordingly to new 802.11n standard will use basic formula for data rate calculation that will be similar to this one:

Data rate (Mbps) = $K \times \text{channel bandwidth factor} \times \text{number of spatial streams} \times \text{coded bits per subcarrier} \times \text{code rate} \times \text{guard interval factor}$

K is constant and equals 0.675 in WWiSE proposal or 13 in TGnSync proposal. *Channel bandwidth factor* is equal to either 20 for 20 MHz channels, or 40 for 40 MHz channels or channel pairs in WWiSE proposal. 20 MHz channels are the baseline, and are assigned a channel bandwidth factor of 1 in TGnSync proposal and 40 MHz channels carry more than

twice the data, and are assigned a channel bandwidth factor of 2.0769 in TgnSync proposal. The *number of spatial streams* can be equal to 1, 2, 3, or 4 and it must be less than or equal to the number of transmission antennas in both proposals. *Coded bits per subcarrier* is either 6 for 64-QAM, 4 for 16-QAM, 2 for QPSK, or 1 for BPSK, whereas in WWiSE proposal BPSK and QPSK are only supported for 20MHz optional channel mode with 1 spatial stream (* in Table 1.). The *code rate* may be 1/2, 3/4 (only WWiSE proposal) when used with BPSK ; 1/2 or 3/4 when used with QPSK or 16-QAM; or 2/3, 3/4, 5/6 when used with 64-QAM. The guard interval factor is parameter used only in TGnSnc proposal. The basic guard interval equals 800 ns, and is assigned the factor 1. 400 ns guard intervals increase throughput slightly, and are assigned a factor of 1.1111.

Combination of different number of spatial streams, coded bits per subcarrier and code rates for two types of channel bands as previously described will lead to different data rates that will be defined by 802.11n standard (Table 1.). We presume that some data rates will be mandatory and some will be optional, like in 802.11a standard, where 6,12, 24 Mbps data rates are mandatory and 9, 18, 36, 48 or 54 Mbps are optional. By combining parameters that have influence on the value of data rate, there may be multiple ways to get to the same data rate. Also, with appropriate combination of described parameters new standard will offer data rates compatible with old 802.11 devices in 2.4 and 5 GHz band.

In a basic 20 MHz channel mode with a single spatial stream and 3/4 cod rate (which are most similar to the legacy radio channel transmission), channel capacity is slightly higher in WWiSE (60.75 Mbps) and TGnSync proposal (65/72.22 Mbps) than in 802.11a standard (56 Mbps) because 4 extra data and fewer pilot subcarriers are used. But, advantage of the TGnSync proposal is that these basic mode is mandatory instead of being optional like in WWiSE proposal. Because of that, another disadvantage of WWiSE proposal shows up, offering data rates lower then 54 Mbps only as an option while they are mandatory offered in TGnSync proposal. WWiSE proposal scores highest channel capacity for every 20MHz channel modulation when compared to TgnSync proposal, because it uses fewer (only 2 instead of 4) pilot subcarriers and higher number of data subcarriers (54 instead of 52). But TGnSync proposal attain approximately 10% higher channel capacity when short guard

interval is used in both bands. When short guard interval is not used, 40 MHz channel capacity is identical in both proposals since they have equal number of data subcarriers. By using all the highest throughput parameters (four 40 MHz spatial streams, with 64-QAM and a 5/6 code rate), in basic mode WWiSE proposal has a maximum throughput of 540 Mbps and TGnSync proposal has a maximum throughput of 540/600 Mbps (higher value of channel capacity is obtained using a short guard interval). Besides basic modes of operation both proposals also offer additional modes. Additional ABM mode of TGnSync with mandatory and optional modulation rates offers one new constellation: 256-QAM, which transmit 8 coded bits per subcarrier with 1/2 and 3/4 code rate, enabling maximum data rates equal to 648/720 Mbps (Table 1.). Additional single stream STBC mode of working in 20 MHz channel band is only offered as optional mode in WWiSE proposal.

It is notable that types of modulation constellations and number of coded bits per subcarrier of new standard would be equal to the one used in 802.11a standard, with exception of ABM mode (256-QAM) proposed by TgnSync, if it will be ratified. However, coding in the new standard will be enhanced, where new convolutional code rates equal to 5/6 will be built in new standard and added to the 1/2, 2/3 and 3/4 code rates defined and used by 802.11a. In addition to the convolutional code supported by the original OFDM specification, the new standard will probably support additional error correction code known as low density parity check (LDPC) code the usage of which is proposed by both groups.

TGnSync proposal achieves higher peak data rates what is probably reflection of TgnSync group goals to support new networked devices and services in the home like sending HDTV or DVD video streams across wireless networks. More aggressive coding, including a larger constellation, and a reduced guard interval are present to improve the data rate in optional mode of TGnSync proposal when compared to WWiSE proposal. Although, TGSync group is heavily oriented towards achieving higher data rates, one element in improving MAC efficiency is usage of a short guard interval. In the 802.11a,g standards as well as the WWiSE proposal, the guard interval is 800 ns and it should be two to four times the delay spread. An 800 ns guard interval allows a 200 ns delay spread, which is much higher than was observed in many environments. Most offices and homes have much smaller delay spread, on the order of 50–100 ns. As we previously notice, if usage of a 400 ns guard interval is built in new standard, it will boost throughput by approximately 10%.

5. Transmission modes

Previous 802.11 PHY specifications had fairly simple transmission modes. The WWiSE proposal has 14 basic transmission modes, depending on 3 items:

1. The number of transmit antennas. It ranges from 1 to 4, although a single antenna is only supported for 40 MHz channels. All 20 MHz channels must use at least two transmit antennas, though they may have only one spatial stream.

2. Whether the frame is used in a greenfield or mixed mode environment. Mixed mode transmissions use physical headers that are backwards-compatible with other OFDM PHYs, while greenfield transmissions use faster physical header.
3. The channel bandwidth, which may be 20 or 40 MHz.

Thus, usage of 2 to 4 antennas for 20 MHz channels in a greenfield and mix mode defines first 6 modes of transmission, where number of spatial streams must be equal to the number of antennas. Usage of 1 to 4 transmit antennas for 40 MHz channels in a greenfield and mix mode defines 8 rest modes of transmission.

There are three transmission modes that the TGnSync proposal calls for. In the mandatory basic MIMO mode, the number of spatial streams is equal to the number of antennas. Each spatial stream is modulated and transmitted identically. Each channel is coded using the same modulation, and sent with the same transmission power. Any changes in transmission rate are based on the implicit feedback of lost acknowledgments. Two optional modes known as basic beamforming and advanced beamforming MIMO (ABM) mode are also proposed by TGnSync, taking advantage of information learned about the radio channel, which is referred to as “closed-loop” operation.

In the basic beamforming MIMO mode, every channel must be coded the same way. Before beginning transmission, TGnSync devices send “sounding” frames to each other to measure the performance of the link. Based on the information gathered from sounding and calibration, beamforming can be used to boost signal quality. Higher signal quality means that a given data rate can be used at longer range. Based on the information from the sounding exchange, the power and coding for the spatial streams is selected. Basic beamforming mode requires that all spatial streams be transmitted at the same power with the same coding. In this mode signal processing advantages are most evident when the number of antennas transmitting a signal is greater than the number of receiving antennas. If the number of spatial streams is less than the number of the transmit antennas, a spatial steering matrix mentioned in second section is used to assign bits to transmission antennas. Third optional ABM mode works in a manner similar to the basic beamforming mode, but with the additional capability of using different transmission power on each transmit stream, as well as the possibility of using a different modulation and code rate on each spatial stream. Like the basic beamforming mode, it requires the gathering of radio status information to calibrate the channel. An optional mode in the advanced beamforming mode allows beamforming to occur in both directions if it is supported in both directions [1, 2, 3].

Although, TGnSync transmission mode proposal requiring closed-loop operation is much more advanced and sophisticated than WWiSE proposal, hardware realization of the closed loop operation in silicon might be quite challenging task. Concept in which sounding frames must be used to measure the channel, and responses must be collected to calibrate the radio channel will impose lot of research effort and higher development price with higher cost of final 802.11n product. On the other hand, the WWiSE proposal uses only open loop operation, which is less sophisticated but

simpler and cheaper to implement. The WWiSE proposal also offers the ability to spread a single encoded stream across multiple antennas without using closed-loop operation. If closed-loop operation were to be problematic to implement in silicon, compromises must be engaged to resolve this issue.

6. MAC enhancements

Although, the aim of this paper is presentation of PHY enhancements that will be incorporated in new 802.11n standard, basic MAC enhancements that will be built in emerging standard will also be described. Both TGnSync and WWiSE adopt techniques to improve the efficiency of the radio channel. Concepts are similar, but the details differ. Both offer some form of block ACKs called frame bursting. By removing the need for one acknowledgment frame for every data frame, the amount of overhead required for the ACK frames, as well as preamble and framing, is reduced. Block acknowledgments will be incorporated in new 802.11n standard. Frame aggregation is also part of both proposals. Many of the packets carried by 802.11 are small. Interactive network sessions, such as telnet and SSH, make heavy use of rapid-fire small packets. Small packets become small frames, each of which requires physical-layer framing and overhead [1, 2, 3]. Combining several small packets into a single relatively large frame improves the data-to-overhead ratio what is important element that must be built in new standard. Frame aggregation is often used with MAC header compression, since the MAC header on multiple frames to the same destination is quite similar. Frame aggregation is an important part in reaching high data rates of 100Mbps and beyond.

Aggregation as designed by the protocol is a bit more intelligent in TGnSync, although this is only a minor advantage. WWiSE's proposal only allows aggregation when the first address field in the MAC header is the same. In an infrastructure network, that address field is the basic service set identifier. All frames from a station to an AP can be aggregated, so the two proposals are identical in the upstream direction. In the downstream direction, WWiSE must use a physical-layer frame burst to change directions. Each new direction must have a new physical layer convergence protocol header. TGnSync can reduce overhead by using a multiple-receiver aggregate frame, and collecting responses from each receiver in the aggregate. Taking full advantage of aggregation opportunities requires more intelligent queuing than is currently implemented. Whether 802.11n offers a huge increase in speed it is likely to depend a great deal on how well improved queuing algorithms are able to coalesce collections of small packets into large aggregates. Since, neither proposal specifies queuing, it will be very useful to define powerful queuing algorithms in both proposals. This will enable incorporation of queuing in new standard, avoiding different queuing performance between vendors.

7. Conclusion

At a very high level, both proposals are similar, though they differ in the emphasis on increasing peak data rates

versus improving efficiency. Although, the goal is 100 Mbps net throughput, the final proposal seems certain to blow past that number, and offers many times (up to 6 or 7) that throughput in maximum configurations. MIMO operation shows up as straightforward, reliable, and suitable technology in realization of these high throughput goals. Each of proposals makes use of MIMO technology in several configurations and provides for backwards compatibility with older (legacy) systems in the same frequency band. Future 802.11n standard will be based on MIMO operation and OFDM technology as channel coding and transport mechanism. Space time block codes will be used for the transmission of a single spatial stream across multiple antennas in some transmission modes of new 802.11n devices. Both proposals support operation in the current 20 MHz channels, with provisions to use double-width 40 MHz channels for reaching extra throughput. It is to be expected that new standard will define work in 20 MHz channels as mandatory, while work in 40 MHz channels will be optional. Combination of different number of spatial streams, coded bits per subcarrier and code rates for two types of channel bands will lead to much higher number of different data rates when compared to older 802.11a,g standards. We presume that some data rates and working modes will be mandatory and some will be optional, like in previous standards. Also, mandatory modes will offer backwards compatibility and interoperability with existing Wi-Fi devices in the 5 GHz and 2.4 GHz bands to ensure strong support of legacy deployments. Besides classical convolutional code rates used in older (802.11a standard), new convolutional code rate 5/6 will probably be incorporated in new standard. In addition to the convolutional code supported by the original OFDM specification, the new standard will probably support additional error correction code known as low density parity check (LDPC) code. On MAC level, block acknowledgments and frame aggregation will be incorporated in new 802.11n standard. TGnSync proposal compared to WWiSE proposal offers the most extensible PHY with higher peak data rates, larger number of different data rates, advanced transmission modes and slightly better PHY hardware realization. These advantages are main reasons why we give little overall advantage in treatment of TGnSync proposal as basis for new standard.

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