Samsung’s Standards and Research Activities Toward 4G

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- Introduction: IT Mega Trends & 4G

- Standards Activity
  - 3GPP LTE
  - 3GPP2 Phase2
  - 802.16e and Beyond
  - ITU-R Activities

- (Part of) Research Activity
  - OFDMA Technology – WiBro as an Example
  - MIMO – Capacity / Coverage Analysis
  - Low Density Parity Check Codes – Performance/Complexity Analysis
  - Cognitive Radio – Technology in IEEE 802.22
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- Cognitive Radio – Technology in IEEE 802.22
Convergence of Different Worlds

Wide range of industry

- Computing
- Communication
- Consumer Electronics
- Contents/Entertainments
- Broadcasting

Drivers

- Global Competition
- Interconnectivity
- Smarter Customers
- De-regulation

Information Convergence
- Device
- Network
- Service
Device Convergence

Convergence Makes Mobile Device to be a Communication Hub

- Mobile Communication
- WiMAX etc.

- Digital Audio
- MP3
- Camera
- Camcoder

- Commerce
- Movie
- Broadcasting
- Internet

- Telematics
- DMB
- Sat.

- Storage device
- Portable game
- Terrestrial DMB

- Chip
- DVDDVD
- TV
- NotePC
- DVD

- W-LAN (Hot-Spot)
Mega Trend & 4G

- Convergence at all the levels: Network, Service, Information
- Ubiquity: connected anywhere, anytime, any device
- Broadband: demanding same quality as in wired line

Affordable price!

Should 4G technologies satisfy all these demands?
Mobile Communication Roadmap

1995
1G (Analog)

1G
(Analog)

2G
(Digital)

3G
(IMT2000)

3G LTE

2000

2005

2010+

4G

Data Rates

~14.4 kbps
144 kbps
384 kbps
<50 Mbps
<100 Mbps

AMPS
ETACS
JTACS
NMT

CDMA/GSM/TDMA

802.11b/PAN

2.4 GHz WLAN

5 GHz WLAN

802.11a/g

CDMA2000 EV-DO/DS
W-CDMA/HSDPA

Bluetooth

High speed WLAN

High speed WLAN

WiBro
IEEE 802.16e

WPAN

RFID
ZigBee
MANet

Low Speed

Medium Speed

High Speed

2G
(Digital)
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**3GPP LTE Milestone**

**UTRAN LTE**
- Improved packet service
  - Max data rate: 100 Mbps (downlink), 50 Mbps (uplink) @ 20 MHz
  - Improved system throughput
- Improved coverage
- Reduced user plane latency: less than 5ms
- Reduced control plane latency: less than 100ms
- Support of scalable system BW: 1.25/2.5/5/10/15/20 MHz

**System Architecture Evolution (SAE)**

**Schedule**

<table>
<thead>
<tr>
<th>Study Item</th>
<th>Work Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement Decision</td>
<td>Commercial: ‘09</td>
</tr>
<tr>
<td>12 ‘05</td>
<td>6 ‘06</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
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<td>12</td>
<td>12</td>
</tr>
<tr>
<td>3 ‘07</td>
<td>6</td>
</tr>
</tbody>
</table>

- Feasibility Study
- Core Specification
- RAN-CN functional split Decision
- Channel Structure, Mobility details Decision
- RAN Architecture, Multiple access scheme Decision
- Study Item TR Approval Stage 2 Completion
Major decisions (RAN1 meeting, Dec. 2005)
- No support of uplink MDC (macro diversity combining)
- Multiple access - DL: OFDMA, UL: SC-FDMA

Current status
- Discussion on UL/DL multiple access details for evaluation
  - Channel structure
  - Scheduling & link adaptation
  - Power control
  - Hybrid ARQ
  - Interference coordination/mitigation
  - Random access procedure
  - Cell search
  - MIMO, Channel Coding
Main objectives

- RAN & CN architecture evolution for new air interface
- Support of heterogeneous access networks
- Mobility between heterogeneous access networks.

Current status

- RAN Architecture
  - Ciphering at anchor decided
  - Location of ARQ and RRC: either in Node B or Anchor (TBD)
- Interworking with legacy 3G network (under discussion)
  - Direct connection with
    - GPRS based 3G PS core vs. IP based interworking
**Phase 1 Evolution**

1. Multi-Carrier EV-DO (CDMA)
2. BW ≤ 20MHz (up to :15FAs)
3. Peak data rate (3Mbps x N)  
   - FL: 45Mbps / RL: 30Mbps
4. Publication: Feb, 2006

**Phase 2 Evolution**

1. OFDM, MIMO, CDMA with FDE
2. BW: ≤ 20MHz (1.25~)
3. Peak data rate (20MHz)  
   - 100Mbps / 50Mbps
4. Publication: April, 2007
Framework proposal for Phase 2

1. Lucent-Nortel-Samsung (LNS) Framework Proposal
   - Two modes (loosely and strictly backward compatible)
   - FDD

2. Numerous proposals from Nokia/Qualcomm/Motorola/Huawei etc. are also being discussed

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Pros &amp; Cons</th>
</tr>
</thead>
</table>
| **Strictly Backward Compatible** | - Co-existing Legacy AT and new AT  
- FL: OFDMA and CDMA multiplexed in time slot  
- RL: CDMA or Hybrid OFDM-CDMA  |
| **Loosely Backward Compatible** | - Smooth Migration from legacy system  
- Performance loss due to backward compatibility  |
| **Pros & Cons** | - Optimized for broadband system  
- Minimum backward compatibility  |

- Legacy AT and new AT in separate carrier  
- Maximize reuse of existing upper layer  
- FL: OFDM / RL: OFDM-CDMA
IEEE 802.16 Standard Evolution

**IEEE 802.16e**
- ~6GHz Multi-cell *(Licensed TDD/FDD)*
- SC2/OFDM/OFDMA
- 24Mbps in 8.75MHz BW(OFDMA)
- OFDMA FFT size: 2K, 1K, 512, 128
- HO in IPv4 or IPv6

**Sponsor Ballot**
- '04.12

**IEEE802.16 f/g/h & j**
- Network Management, Licensed-Exempt enhancement
- Multi-Hop Relay

**'05.12 Publication As Standard**

**PHY/MAC optimization and Relay enhancement**

**WiBro**
- PHF Harmonization
- MAC Harmonization

**'04.10 Phase I rev.**

**'05.6 Draft 9**

**PHY Harmonization**
- Max 50Mbps
- AAS, MIMO, Relay N/W

**'05.4Q Phase II**

**'05.12**

**Commercial**

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*Samsung Electronics*
### 802.16 MMR TG (802.16j)

**Standardization**
- **Phased Approach**
  - Objective
  - Transparency to MS
- **802.16 MMR Work Scope**
  - Infrastructure Relay, No modification to 16e MS, 16e mobile access reuse
  - Focus: Air interface design of BS-RS link (MAC Layer)
- **Main Benefits**
  - Rapid deployment, Reduce OPEX
- **Key Players**
  - KDDI, Samsung, Motorola

**Timeline**
- '06: Coverage Expansion
- '07: Capacity Increase
- '08: SA Approval

**Graphical Representation**
- Fixed Infrastructure Relay
- MMR BS
- RS
- MMR: Mobile Multi-hop Relay

**Diagram**
- 16e MS (Fixed Infrastructure Relay)
- MMR BS
- RS
- 16e MS (MMR: Mobile Multi-hop Relay)
ITU-R WP-8F Overall Workplan

<table>
<thead>
<tr>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009+</th>
</tr>
</thead>
<tbody>
<tr>
<td>MARKET &amp; TECHNOLOGY</td>
<td>MARKET &amp; TECHNOLOGY</td>
<td>APPROVED</td>
<td>APPROVED</td>
<td>NEXT!</td>
<td>NEXT!</td>
</tr>
<tr>
<td>RADIO NEEDS &amp; CANDIDATE BANDS</td>
<td>RADIO ASPECTS II</td>
<td>APPROVED</td>
<td>APPROVED</td>
<td>NEXT!</td>
<td>NEXT!</td>
</tr>
<tr>
<td>SHARING STUDIES</td>
<td>CPM TEXT</td>
<td>SERVICES</td>
<td>SERVICES</td>
<td>SERVICES</td>
<td>SERVICES</td>
</tr>
<tr>
<td>RULE &amp; PROCESS DEVELOPMENT</td>
<td>RULE &amp; PROCESS DEVELOPMENT</td>
<td>RULE &amp; PROCESS DEVELOPMENT</td>
<td>RULE &amp; PROCESS DEVELOPMENT</td>
<td>RULE &amp; PROCESS DEVELOPMENT</td>
<td>RULE &amp; PROCESS DEVELOPMENT</td>
</tr>
</tbody>
</table>

Circular Letter to External Organizations

“Principles”

Radio Framework

Requirements
Strategy for IMT-Advanced Standards

Regional

- IEEE
- SDO (TTA, ARIB, CCSA, TIA)
- 3GPP/2

Global

802.16 Evolution

Proposed IMT-Advanced frameworks

ITU-R

Rule & Process
- Open standard
- Consensus Building
- Evaluation Criteria
- IPR Policy

ITU Global Core Specification

IMT-2000 Enhancement
## ITU-R Candidate Spectrum Bands

<table>
<thead>
<tr>
<th>Candidate band (MHz)</th>
<th>Supporting Countries</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>410-430</td>
<td>Brazil</td>
<td></td>
</tr>
<tr>
<td>450-470</td>
<td>Russia, Cameroon, USA, CHN</td>
<td></td>
</tr>
<tr>
<td>470-806/862</td>
<td>USA, CAN, CHN, KOR</td>
<td>Regional Harmonization: Asia/Pacific</td>
</tr>
<tr>
<td>2300-2400</td>
<td>Brazil, CHN, KOR, AUS</td>
<td></td>
</tr>
<tr>
<td>2700-2900</td>
<td>Sweden</td>
<td>Opposition by US, EU</td>
</tr>
<tr>
<td>3400-4200</td>
<td>Europe, JPN, KOR</td>
<td>For Mobile + Nomadic (Sharing issue against Fixed Satellite Service)</td>
</tr>
<tr>
<td>4400-4900</td>
<td>JPN</td>
<td></td>
</tr>
</tbody>
</table>

### One Different View: Technical Neutrality
- To use any mobile technology in the band allocated to mobile services
- US, CAN, AUS and NZ support it.

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**IMT-2000 including enhancement**

**IMT-Advanced**
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Mega Trend: Mobile Communication

- Data Service: Fixed ➔ High Speed Mobile Comm.

Present

- 1995: 1G (Analog)
- 2000: CDMA
- 2005: OFDMA
- 2010+: 4G

- Data Transmission Speed
  - ~14.4 kbps
  - 144 kbps
  - 384 kbps
  - 50 Mbps
  - 200 Mbps
  - 1 Gbps

- Mobility
  - Fast
  - Slow

- WiBro Evol.
- WiBro
- 802.11b
- 802.11a/g
- 802.11n

- 2.4 GHz WLAN
- 5 GHz WLAN
- PAN

- CDMA
- OFDMA

- 2G (Digital)
- 3G (IMT2000)
- 3.5G

WiBro

Mega Trend: Mobile Communication

Samsung Electronics
WiBro Overview

- Wireless Broadband: WiBro
- 3.5G Wireless Mobile Communication System
- High-speed Portable Internet
- Based on IEEE802.16-2004 / TGe+ and TTA PG302
WiBro System Requirements

- OFDMA based
- Investigating feasibility of various new technologies

<table>
<thead>
<tr>
<th>Major System Parameters</th>
<th>Radio Access Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplexing</td>
<td>TDD</td>
</tr>
<tr>
<td>Multiple Access</td>
<td>OFDMA</td>
</tr>
<tr>
<td>Nominal Channel BW</td>
<td>8.75 [MHz]</td>
</tr>
</tbody>
</table>
|                       | | Spectral Efficiency [bps/Hz/cell(sector)] | Max. DL / UL = 6 / 2  
|                       | | | Aver. DL / UL = 2 / 1 |
|                       | | Handoff | ≤ 150 [ms] |
|                       | | Throughput (per user) | Max. DL / UL = 3 / 1 [Mbps]  
|                       | | | Min. DL / UL = 512 / 128 [Kbps] |
# WiBro System Key Parameters

<table>
<thead>
<tr>
<th>Item</th>
<th>802.16e (WiBro/WiMAX)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channel bandwidth</strong></td>
<td>1.25 / . / 5 / . / 10 / . / 20 MHz (Multi-mode)</td>
</tr>
<tr>
<td><strong>Duplexing</strong></td>
<td>FDD / TDD</td>
</tr>
<tr>
<td><strong>Peak Rate</strong></td>
<td></td>
</tr>
<tr>
<td>FDD @5M</td>
<td>DL(2x2): 24<del>29Mbps (Control OH: 23</del>15%), UL(1x1): 7.7Mbps</td>
</tr>
<tr>
<td>TDD (2:1) @10M</td>
<td>DL(2x2): 30~34Mbps, UL(1x1): 4Mbps</td>
</tr>
<tr>
<td><strong>Multiple Access</strong></td>
<td></td>
</tr>
<tr>
<td>Downlink</td>
<td>OFDMA</td>
</tr>
<tr>
<td>Uplink</td>
<td>OFDMA</td>
</tr>
<tr>
<td><strong>Frame length</strong></td>
<td>2, 2.5, 4, 5, 8, 10, 12.5, 20 ms</td>
</tr>
<tr>
<td><strong>Tone space/Symbol duration</strong></td>
<td>9.765625 kHz / 115.2 us (1/8 CP)</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>QPSK, 16QAM, 64QMA (DL only)</td>
</tr>
<tr>
<td><strong>FEC</strong></td>
<td>CC, CTC, BTC, LDPC (1/12 ~ 5/6)</td>
</tr>
<tr>
<td><strong>Subchannelization</strong></td>
<td>Diversity / AMC subchannel</td>
</tr>
<tr>
<td><strong>HARQ</strong></td>
<td>Asynch.: Chase, IR (10ms ≤ latency ≤ 20ms)</td>
</tr>
<tr>
<td><strong>Handover</strong></td>
<td>Soft HO, FSS, HHO</td>
</tr>
<tr>
<td><strong>MIMO</strong></td>
<td></td>
</tr>
<tr>
<td>Downlink</td>
<td>TD / HD / SM / Precoding / AAS</td>
</tr>
<tr>
<td>Uplink</td>
<td>TD / SM</td>
</tr>
</tbody>
</table>
WiBro Protocol Stack

- Physical Layer and MAC layer
- Upper layer functionalities for Mobility

- Core network interface

- Mobile WiMAX = WiBro

802.16e

802.16-2004

Scalability, H-ARQ, MIMO etc.
WiBro Network Reference Model

- **Access Network (PSS - RAS)**
- **Core Network (RAS - ACR, ACR - ACR)**

**Diagram:**
- Public IP Network
- Operator’s IP Network
- HA
- AAA
- ACR
- RAS
- PSS

**Legend:**
- ACR: Access Control Router
- RAS: Radio Access Station
- PSS: Personal Subscriber Station
Forward Error Correcting Codes

- **Future system requires higher data throughput**
  - Need a Fast Decoder
  - Need higher performance in high code rate

<table>
<thead>
<tr>
<th>System Service</th>
<th>System Requirement</th>
<th>Channel code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2G</strong></td>
<td></td>
<td>Voice</td>
</tr>
<tr>
<td>Voice</td>
<td>Voice : ~19.2Kbps</td>
<td>Voice : Conv. code</td>
</tr>
<tr>
<td><strong>3G</strong></td>
<td>Voice : ~19.2Kbps</td>
<td>Low Data rate</td>
</tr>
<tr>
<td>Voice</td>
<td>Data : ~2Mbps</td>
<td>Voice : Conv. code</td>
</tr>
<tr>
<td>Data : Turbo code</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4G</strong></td>
<td>Voice : Conv. code</td>
<td>high Data rate</td>
</tr>
<tr>
<td>Voice</td>
<td>Data : 100Mbps ~ 1Gbps</td>
<td></td>
</tr>
<tr>
<td>Data : ??</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fast decoder having higher decoder throughput is needed!!!**
**LDPC code** (Low Density Parity Check)

- **LDPC code**
  - LDPC code can be defined by Parity Check matrix (H-matrix)
  - Based on the H-Matrix, Factor graph representation is used

- **LDPC decoder**
  - Parallel decoding Architecture by using factor graph representation
  - Simple Operation is used for decoding

- **LDPC Encoder**
  - Encoding process is operated by using the defined H-matrix
  - Back-substitution tech. can be used for Encoder
Performance (R = 1/3): Room to enhance

Channel coding performance: AWGN, QPSK, K=1152 bits, R=1/3

- LDPC, parallel, R=1/3
- TC, R=1/3

BLER vs Eb/N0 [dB] graph
Channel coding performance: AWGN, QPSK, K=1152 bits, R=1/2

- LDPC, parallel, R=1/2
- TC, R=1/2
Performance (R = 2/3)

Channel coding performance: AWGN, QPSK, K=1152 bits, R=2/3

- LDPC, parallel, R=2/3
- TC, R=2/3
Performance ($R = \frac{3}{4}$)

Channel coding performance: AWGN, QPSK, $K=1152$ bits, $R=\frac{3}{4}$

- **LDPC, parallel, $R=\frac{3}{4}$**
- **TC, $R=\frac{3}{4}$**

Blind Error Rate (BLER) vs. $Eb/N0$ [dB]
Performance (R = 1/3 ~ 3/4)

LDPC outperforms Turbo when encoding Longer Packets (> 4K-bit) or at High Code (R > 1/2)
## Complexity Comparison

LDPC has bigger decoding throughput than Turbo – what about memory requirements?

<table>
<thead>
<tr>
<th>Used Algorithm</th>
<th>LDPC</th>
<th>TC</th>
<th>Complexity (LDPC / TC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LBP Min-Sum + Offset</td>
<td>Max Log Map + extrinsic scaling</td>
<td></td>
</tr>
<tr>
<td>Number of Iterations</td>
<td>20</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Total cost (R=1/3)</td>
<td>38.5K x 20 = 770K</td>
<td>171K x 8 = 1,368K</td>
<td>56%</td>
</tr>
<tr>
<td>Total cost (R=1/2)</td>
<td>28.8K x 20 = 576K</td>
<td>171K x 8 = 1,368K</td>
<td>42%</td>
</tr>
<tr>
<td>Total cost (R=3/4)</td>
<td>20.6K x 20 = 412K</td>
<td>171K x 8 = 1,368K</td>
<td>30%</td>
</tr>
</tbody>
</table>

Source: 3GPP TSG-RAN1 #44bis: R1-060874, Intel-ITRI-LG-Mitsubishi-Motorola-Samsung-ZTE
### Example MIMO System: IEEE 802.16e

#### DL (No. BS Ant) vs. UL (No. MS Ant)

<table>
<thead>
<tr>
<th>Open-loop</th>
<th>2 Tx</th>
<th>3 Tx</th>
<th>4 Tx</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Single user: $N_s = 2$ (VE) | $\sqrt{(1)}$ TD (A) Alamouti | $\sqrt{(3)}$ SMSM (C) FDFR w/ permutation | $\sqrt{(6)}$ FDFR | $\cdot$ Spatial rate ($N_s$) = 1  
$\cdot$ Permutation is subcarrier-based |
| Open-loop | $\sqrt{(4)}$ SM Double-Alamouti w/ permutation | $\sqrt{(7)}$ SM Double-Alamouti w/ permutation | $\cdot$ $N_s = 2$ (VE)  
$\cdot$ Rate control possible  
$\cdot$ (Single FEC) |
| SM (C) | $\sqrt{(2)}$ SM | $\sqrt{(5)}$ SM | $\sqrt{(8)}$ SM | $\cdot$ $N_s = N_t$ (VE)  
$\cdot$ Rate control possible  
$\cdot$ (Single FEC) |
| Closed-loop | General Precoding | $\sqrt{(9)}$ SU/MU precoding | | $\cdot$ Feedback of Beamforming vector/matrix index.  
$\cdot$ Rate control possible  
$\cdot$ Rate 1 precoding = AAS |
| Sounding | SVD | $\sqrt{(10)}$ Singular Value Decomposition | | $\cdot$ Channel sounding utilization (TDD channel reciprocity)  
$\cdot$ Rate control possible  
$\cdot$ Calibration needed |

<table>
<thead>
<tr>
<th>UL (No. MS Ant)</th>
<th>2 Tx</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-loop</td>
<td>TD (A)</td>
<td>$\sqrt{(12)}$ Alamouti</td>
</tr>
<tr>
<td></td>
<td>SM (C)</td>
<td>$\sqrt{(13)}$ SM</td>
</tr>
</tbody>
</table>
**Multi Antenna: Simulation Environment**

**Conditions**

<table>
<thead>
<tr>
<th>Channel Model</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCM (Urban Macro, 3kmph)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scheduler</th>
<th>RR, PF, Max. C/I</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Antenna configuration</th>
<th>SISO, MIMO (A, B, C)*</th>
</tr>
</thead>
</table>

**MCS level**

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1</td>
<td>1/3</td>
<td>QPSK</td>
<td>6</td>
<td>1/2</td>
<td>16QAM</td>
<td>10</td>
<td>2/3</td>
<td>64QAM</td>
</tr>
<tr>
<td>2</td>
<td>1/2</td>
<td>QPSK</td>
<td>7</td>
<td>2/3</td>
<td>16QAM</td>
<td>11</td>
<td>3/4</td>
<td>64QAM</td>
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<tr>
<td>3</td>
<td>2/3</td>
<td>QPSK</td>
<td>8</td>
<td>3/4</td>
<td>16QAM</td>
<td>12</td>
<td>5/6</td>
<td>64QAM</td>
</tr>
<tr>
<td>4</td>
<td>3/4</td>
<td>QPSK</td>
<td>9</td>
<td>5/6</td>
<td>16QAM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5/6</td>
<td>QPSK</td>
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</tbody>
</table>

* Matrix A: Diversity mode, Matrix B: Hybrid mode, Matrix C: SM mode
Single Antenna Case

- **MCS level distribution**
  - **Cell Radius = 1 km**
  - **1 stream transmission**

![MCS level distribution graphs](image-url)

- **Max. C/I**
- **RR**
- **PF**

Samsung Electronics
MIMO: Matrix A (Diversity Mode)

- **MCS level distribution**
  - Cell Radius = 1 km
  - 1 stream transmission
MIMO: Matrix B (Hybrid Mode)

- MCS level distribution
  - Cell Radius = 1 km
  - 2 stream transmission
MIMO: Matrix C (Spatial Multiplexing Mode)

- MCS level distribution
  - Cell Radius = 1 km
  - 4 stream transmission
MIMO Modes Comparison

Scheduler: PF

SISO

Mat. A

Mat. B

Mat. C
Cognitive Radio Technology Overview

Autonomous Dynamic Spectrum Utilization

Sense
Model of Air Interface
Model of RF Environment

Adapt
Model of Radio

React
Model of Policies
Model of User

Characterize
Model of Network
Model of Air Interfaces

Source: XG DARPA
Cognitive Radio Technology Overview

- Agile hardware
  - Software Defined Radio
  - Adaptive wideband transceiver architectures

- Radio scene awareness
  - Wideband radio sensing algorithms (very low detection thresholds)
  - Predictive channel models
  - Radio scene analysis

- Regulations/policies
  - Radio certification
  - Standardization

- Security
  - Theoretical limits

- Models of networks
  - Network-centric vs. device-centric designs
  - Horizontal vs. vertical overlay

- Adaptation of radio access technology
  - Multidimensional (time, frequency, space)
  - Adaptive waveforms, modulation, coding, dynamic frequency selection, transmit power control, adaptive bandwidth, MIMO

- Cooperative techniques
  - Cooperative sensing
  - Cooperative transmission
  - Distribution of control information
  - Spectrum sharing/etiquette

Network-centric vs. device-centric designs
Horizontal vs. vertical overlay
Cooperative techniques
### (Part of ) Key Technical Areas

<table>
<thead>
<tr>
<th>Tree 1</th>
<th>Tree 2</th>
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<tbody>
<tr>
<td>1 Software Defined Radio (Reconfigurable Radio)</td>
<td>Antenna</td>
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<td>High-Speed A/D, MEMS</td>
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<td>Agile Radio</td>
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<td>2 Channel Sensing</td>
<td>Device Sensing Technology</td>
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<td>Distributed and Cooperative Sensing</td>
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<td>Self-Interference Avoidance</td>
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<td>Spatial Sensing</td>
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<td>3 Spectrum Awareness</td>
<td>Predictive Radio Channel Models</td>
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<td>Database Maintenance</td>
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<td>Dynamic Spectrum Management</td>
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<td>4 Spectrum Sharing Protocols</td>
<td>Inter-System (with other types of unlicensed band devices)</td>
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<td>Dynamic Power Management</td>
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<td>Game Theory (Interactive Decision Problems)</td>
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<td>5 Cooperative Techniques</td>
<td>Cooperative Sensing</td>
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<td>Cooperative Transmission</td>
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<td></td>
<td>Cooperative Spectrum Sharing</td>
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</table>
IEEE 802.22 the first standard on cognitive radio networks

- Broadband Wireless Regional Area Network (WRAN).
- Scope: air interface for fixed point-to-multipoint wireless regional area networks operating in the VHF/UHF TV broadcast bands between 54 MHz and 862 MHz.

End-to-End Reconfigurability (E²R) European project

“devise, develop and trial architectural design of reconfigurable devices and supporting system functions to offer and expanded set of operational choices to the users, application and service providers, operators, regulators in the context of heterogeneous mobile radio systems”.

Wireless World Research Forum

IEEE 802.22: Key Requirements

- **Services:** packet-based broadband Internet (VoIP, data, video)
- **Coverage:** 33 to 100 km, 512 users minimum, 50/1 over-subscription ratio
- **Minimum peak throughput rate at edge of coverage:**
  - 1.5 Mbits/s per subscriber in the forward direction
  - 384 kbits/s per subscriber in the reverse direction
  - Link availability 99.9% of time
- **0.5 bit/sec/Hz < spectral efficiency < 5 bits/sec/Hz**
- **Duplex mode**
- **Unlicensed operation in TV bands**
  - UHF/VHF 54 MHz - 862 MHz
  - 6, 7 or 8 MHz bandwidth channels worldwide
- **Master/slave relationship between base station and user terminals**
- **Spectrum sensing, dynamic frequency selection, transmit power control, cooperative sensing, timing requirements for interference control**
- **Adjacent channel interference mitigation, co-channel interference avoidance**
- **Protection of incumbent licensed spectrum users**
  - Analog TV (NTSC) within Grade-B contour
  - Digital TV within noise-protected contour
  - Part 74 devices in the US (wireless microphones, wireless intercoms...)
  - Public safety
  - Public Land Mobile Radio System (PLMRS) services
- **Spectrum sharing between 802.22 networks**
- **Coexistence with other license-exempt devices**
### IEEE 802.22: Proposals and Technologies

<table>
<thead>
<tr>
<th>4 complete proposals</th>
<th>3 proposals</th>
<th>2 proposals</th>
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<tbody>
<tr>
<td>Samsung (GSR,SAIT,STA)</td>
<td>Institute for Infocomm Research</td>
<td>Nanotron</td>
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<td>Philips/France Telecom</td>
<td>Nextwave</td>
<td>Huawei Technologies</td>
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<td>ETRI/SamsungElectromechanics/</td>
<td>Thomson</td>
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<td>Georgia Tech</td>
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<td>Runcom/STMicroelectronics</td>
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<tr>
<td>802.16e baseline PHY and MAC</td>
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<td>Waveform-based access (short pulses and chirp pulses)</td>
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<td>Modified PHY and MAC for cognition</td>
<td>Modified PHY and MAC for cognition</td>
<td>Basic multiple access and frame structures</td>
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<td>Network initialization and</td>
<td>Spectrum sensing (Thomson)</td>
<td>No interference and coexistence procedures</td>
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<tr>
<td>association protocols</td>
<td>No interference and coexistence procedures</td>
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<tr>
<td>Wideband sensing techniques</td>
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<td>(hardware, baseband)</td>
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<td>Cooperative sensing decisions</td>
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<td>Radio scene analysis</td>
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<td>Dynamic frequency selection</td>
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<td>Cooperative transmit power</td>
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<td>control</td>
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<td>Interference management</td>
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<td>Spectrum sharing protocols</td>
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<td>Coexistence protocols</td>
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<td>Multiple antenna techniques</td>
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<td>Security</td>
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We believe that WWRF is one of the greatest world-renowned groups to discuss future technology and more toward future global standards.
Thank You!

dspark@samsung.com