Development of OFDM/TDMA-based Broadband Wireless Access Systems
--Dynamic Parameter Controlled OFDM/TDMA (DPC-OF/TDMA) System--

Seiichi Sampei
Department of Information and Communications Technology, Osaka University

Hiroshi Harada
Wireless Access Group
National Institute of Information and Communications Technology
Requirements for Fourth Generation Wireless Access Networks

- Flexible accessibility to Ubiquitous Networks composed by cellular, hot spots, PAN and some other private networks
- Broadband services ranging from short packet to large file downloading
- High spectral efficiency (more than 10bit/s/Hz)
- Support to various terminal mobility
Basic Policy of our Radio Resource Management
-- Single slot or multi-slot?
-- Spreading or non spreading?

Primary policy
- TDMA
  -- Dedicated slot
  -- No spreading

Secondary policy
- Resource share by another users (SDMA) if unused resource exists.
Solutions for these requirements

- Adaptive modulation
- OFDM/TDMA
- One cell reuse

Segmentation of radio resource in both time and frequency domain

Maximization of commonality and SDR technologies

Dynamic Parameter Controlled OFDM/TDMA (DPC-OF/TDMA)

- Flexible available user rate
  - High peak and average user rate
- Flexible radio resource management
  - Large dynamic range of packet size)
- Flexible accessibility to various networks
  - LAN: 802.11a/b/g
  - 3G and 4G cellular
  - Others
Key Technologies for DPC-OF/TDMA (1)
-- One Cell Reuse Scheme using OFDM-based Adaptive Modulation --

Partial Non-Power Allocation

Desired signal

No interference

Interference signal

High quality channel

Desired signal

OFDM-based Adapt. Mod.

No negotiations for slot assignment between adjacent cells can simplify slot assignment process
Key Technologies for DPC-OF/TDMA (2)
-- Segmentation of radio resource in both time and frequency domain --

256 bytes transmission using $r = \frac{1}{2}$ channel encoder

102.4 Mbit/s TDMA

Freq.

50 $\mu$s

(Segmentation only in time domain)

250 $\mu$s

(Segmentation in both time and frequency domain)

102.4 Mbit/s OFDM/TDMA

Preferable minimum slot length is 100 $\mu$s or more
MAC Layer for DPC-OF/TDMA
MAC frame Configuration

Downlink:
- FCMS
- MDS
- MDS
- MDS
- Slot guard
- MDS
- MDS
- Frame guard

Uplink:
- ACTS
- MDS
- MDS
- MDS
- MDS

FCMS (Downlink): Frame Control Message Slot
Control signal, broadcast message, MDS usage

ACTS (Uplink): Activation Slot
Association request

MDS (Down/Up): Message Data Slot
Traffic Channel Data
Physical Layer for DPC-OF/TDMA
Slot Format for Physical Layer

- 1 PHY frame = 10 slots = 2.5 ms

- 64 subcarriers
- 64 * 12 = 768 subcarriers

- 125 kHz * 768 = 96.125 MHz

- One MAC packet is mapped onto 1 physical unit

- 1 PHY unit
- 1 Subchannel

[Diagram showing the slot format with time and frequency axes, 1 PHY frame composed of 10 slots, each slot containing 64 subcarriers, and the frequency bandwidth calculated as 125 kHz * 768 subcarriers.]
Development of OFDM Adaptive Modulation (1)
-- Simple AMS and AMS with MTPC --

Simple OFDM adaptive modulation scheme (AMS)

OFDM AMS with multilevel transmit power control (MTPC)

This surplus power does not improve data rate

Joint allocation of modulation level and transmit power

Maximizing data rate

More feedback necessary!!
Development of OFDM Adaptive Modulation (2)
-- Variable Coding Rate OFDM AMS --

Simple OFDM Adaptive Modulation

Variable Coding Rate (VCR) OFDM Adaptive Modulation

Smaller SINR gaps

Increase of MCS by introduction of variable coding rate can reduce surplus power and can enhance throughput

However,

Conventional punctured code
- coding rate is NOT flexible

Two stage punctured coding
- Conventional punctured code
- regular bit deletion
Modulation and Coding Scheme for VCR AMS

<table>
<thead>
<tr>
<th>Mod.</th>
<th>$r_1$</th>
<th>$r_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>64QAM</td>
<td>3/4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>60/59</td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td>6/5</td>
</tr>
<tr>
<td>16QAM</td>
<td>5/6</td>
<td>140/139</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td>11/10</td>
</tr>
<tr>
<td>QPSK</td>
<td>7/8</td>
<td>100/99</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>36/35</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td>1</td>
</tr>
<tr>
<td>BPSK</td>
<td>1/2</td>
<td>5/4</td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td>1</td>
</tr>
<tr>
<td>1/2 BPSK</td>
<td>1/2</td>
<td>5/4</td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td>1</td>
</tr>
</tbody>
</table>

**Convolutive coding**

- $r = 1/2$
- $K = 7$

**1st bit puncturing rate $r_1$**

**2nd bit puncturing rate $r_2$**

Two-stage bit puncturing stage

[2nd bit puncturing]

One bit is deleted every $i$ bits

$$r_2 = \frac{i}{i-1}$$
MAC packet mapping onto PHY slot  
-- MDS mode selection --

- Basic Mode
  - 128 bytes is mapped onto one PHY unit (410 kbit/s – 3.7 Mbit/s; 1 subchannel)  
    (44 Mbit/s for mode 3; 12 subchannels)
- Extended Mode for MDS Transmission
  - Multiple of 128 bytes is mapped onto one PHY unit in GOOD channel conditions
  - Fraction of 128 bytes is mapped onto one PHY unit in BAD channel conditions

<table>
<thead>
<tr>
<th>MDS mode ( (l) )</th>
<th>Payload size ( D(l) ) [bytes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>128</td>
</tr>
<tr>
<td>4</td>
<td>256</td>
</tr>
<tr>
<td>5</td>
<td>384</td>
</tr>
<tr>
<td>6</td>
<td>512</td>
</tr>
</tbody>
</table>

While keeping MAC protocol as simple as possible, advantage of adaptive modulation in PHY is maximized

Mode could be extended by MIMO introduction
Calculation for available MDS mode

OFDM subchannel (64 subcarriers)

Calculate maximally allocatable number of MDS bits in all the subcarriers ($N_{total}$) in an OFDM AMS/TDMA subchannel

$$D(l) \leq N_{total} < D(l+1)$$

Mode $l$ will be selected

<table>
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<th>MDS mode ($l$)</th>
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PHY Configuration

- **MAC Layer**
  - Tx data buffer
  - PHY Configuration
  - Rx data buffer

- **OFDM Tx**
  - VCR encoder
  - Symbol mapper
  - IFFT + GI ins.
  - GI rem. + FFT
  - Symbol Demap.
  - VCR decoder

- **OFDM Rx**
  - Pilot signal
  - SINR estimator
  - MCS selector
  - MCS demand feedback (higher error protection)

- **MCS Request Detector**
  - MDS mode info.
  - MCS info.
  - BER/FER curves
  - MCS info.
Performance Evaluation of DPC-OF/TDMA
## Simulation Conditions

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol rate</td>
<td>100 ksymbols/s</td>
</tr>
<tr>
<td>Num. of subcarriers and time slots</td>
<td>64 subcarriers 1 slot/frame</td>
</tr>
<tr>
<td>FEC</td>
<td>Convolutional coding (r = 1/2, K = 7)</td>
</tr>
<tr>
<td>Max.Tx Power</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>AP: 15 dBi, TE: 3 dBi</td>
</tr>
<tr>
<td>Cell radius</td>
<td>100 m</td>
</tr>
<tr>
<td>Cell model</td>
<td>3-sector, 7 cell wrapping</td>
</tr>
<tr>
<td>Path loss model</td>
<td>ITU-R outdoor to indoor &amp; pedestrian</td>
</tr>
<tr>
<td>Shadowing</td>
<td>Log-normal (σ = 8 dB)</td>
</tr>
<tr>
<td>Channel model</td>
<td>Exponential decaying 12-spike Rayleigh (rms delay spread = 200 ns)</td>
</tr>
<tr>
<td>$f_D$</td>
<td>50 Hz</td>
</tr>
</tbody>
</table>
### Selection Ratio for MDS

**Graph:**
- **Y-axis:** Selection ratio (%)
- **X-axis:** MDS mode
- Categories: OFDM AMS/MTPC, VCR OFDM AMS, Conventional OFDM AMS
- Highest selection ratio is for MDS mode 6.

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**Legend:**
- Higher data rate denotes a higher selection ratio.
Average throughput performances

Average throughput (Mbit/s) per one PHY unit

Block size

Block size (for averaging interference and noise level measurement)

Average total throughput

100 times more || > 100 Mbit/s
Conclusions

- Development of DPC-OF/TDMA
  - One cell reuse TDMA
  - OFDM-based adaptive modulation
- Simple MAC and flexible PHY
- Large dynamic range of supportable
- System throughput of more than 100 Mbit/s achievable
Slot Format for MAC Sub-Layer

From Higher Layer

- Header
- Payload
  - FCMP, ACTP, MDP
- Preamble
- Unique Word
- Packet
- Guard time

1 MAC slot (FCMS, ACTS, MDS)

Packet

Map onto PHY slot
Types of MAC Packet Format

- **FCMS (Frame Control Message Slot)**
  - Downlink only
  - FCMP (Frame Control Message Packet) is transmitted
  - Control signal, broadcast message, MDS usage

- **ACTS (ACTivation Slot)**
  - Uplink only
  - ACTP (ACTivation Packet) is transmitted
  - Association request

- **MDS (Message Data Slot)**
  - Both Downlink and Uplink
  - MDP (Message Data Packet) is transmitted
  - Traffic data
Encoding Process
-- Convolutional Encoding with Two Stage Bit Puncturing --

MAC data

Tail bits

Convolutional coded word

- $r_1 = 1/2$ convolutional coding
  - 2/3
  - 3/4
  - 5/6
  - 7/8

- $r_2 = 1$ convolutional coding
  - 11/10
  - 1
  - 1
  - 1
  - 1

1 bit is deleted every 11 bits

- 1st bit puncturing
- 2nd bit puncturing

Mapping to subcarriers

Modulation, IFFT