One Cell Reuse OFDM/TDMA using subcarrier level adaptive modulation for broadband wireless access systems

Seiichi Sampei
Department of Information and Communications Technology, Osaka University
Outlines

- Subcarrier level adaptive modulation broadband broadband OFDM/TDMA
  - Why subcarrier level adaptive modulation necessary?
  - Do both subcarrier level TPC and adaptive modulation necessary?
  - To what extent we can expect for MAC flexibility?

- Single carrier transmission for broadband TDMA
  - How to make single carrier transmission as flexible as OFDM?
    - Spectrum compatibility
    - Interference immunity
    - Dynamic resource management capability
Required flexibility in Broadband Wireless Access (Downlink)

- Flexible available user rate
  - High peak and average user rate in the Downlink
  - One-cell reuse (no spreading)
- 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

- Subcarrier Level Adaptive modulation for OFDM/TDMA (no intra-cell interference)

Segmentation of radio resource in both time and frequency domain

maximization of commonality and SDR technologies

Dynamic Parameter Controlled OFDM/TDMA (DPC-OF/TDMA)
Why subcarrier level adaptive modulation in OFDM?
Theoretical Background (reason for no spreading)

- Transmission Capacity is **upper limited** by Shannon’s Theory
  - Microscopic control based on Water-Filling rather than partial averaging

- How to cope with interference
  - Known interference: canceller
  - Unknown interference: avoidance

- Key: Adaptive Modulation

- Data

- Wireless Channel (Shannon Capacity)

- Channel Capacity Control
  - TPC
  - Dynamic Channel Selection

- Knowledge on channel
  - Freq. Transfer function
  - known interference
  - unknown interference

- Receiver
  - Diversity
  - Equalizer +decode
Enhancement of Robustness to Inter-Cell Interference using subcarrier level adaptive modulation

Partial Non-Power Allocation

Desired signal

No interference

Interference signal

High quality channel

OFDM-based Adapt. Mod.

No negotiations for slot assignment between adjacent cells can simplify slot assignment process
Do both subcarrier level TPC and subcarrier level adaptive modulation necessary?
Comparison of Simple adaptive modulation and subcarrier level TPC introduced adaptive modulation

Simple OFDM adaptive modulation

OFDM adaptive modulation with subcarrier level TPC

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

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

Smaller SINR gaps
Two stage punctured coding

<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>

Convolutional coding

$K = 7$

$1^{st}$ bit Puncturing rate $r_1$

$2^{nd}$ bit Puncturing rate $r_2$

Two-stage bit puncturing

[2$^{nd}$ bit puncturing]

One bit is deleted every $i$ bits

$r_2 = i/(i-1)$

OFDM AMS

$r = 1/2$
To what extent we can expect for MAC flexibility?
Calculation for available MAC mode

OFDM subchannel (64 subcarriers)

Calculate maximally allocatable number of MAC (payload) bits in all the subcarriers \(N_{\text{total}}\) in an OFDM AMS/TDMA subchannel

\[
D(l) \leq N_{\text{total}} < D(l + 1)
\]

Mode \(l\) will be selected

<table>
<thead>
<tr>
<th>MAC 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>
Slot Format for Physical Layer

1 PHY frame = 10 slot = 2.5 ms

1- Subchannel

1-PHY unit

One MAC packet is mapped onto 1-physical unit
MAC packet mapping onto PHY slot
-- Payload size 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 MAC 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>Index ((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.
## Simulation Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</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 ($\sigma = 8$ dB)</td>
</tr>
<tr>
<td>Channel model</td>
<td>Exponential decaying 12-spike Rayleigh ($\text{rms delay spread} = 200$ ns)</td>
</tr>
<tr>
<td>$f_D$</td>
<td>50 Hz</td>
</tr>
</tbody>
</table>
Selection Ratio for MAC

Adapt. Mod. with subcarrier TPC
Adapt. Mod. with two-stage punc. code
Adapt. Mod. without subcarrier TPC

<table>
<thead>
<tr>
<th>MAC 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>

Average user rate (1 PHY unit):
- w/ Subcarrier TPC: 1.1 Mbit/s
- 2-stage punc. code: 1.05 Mbit/s

Higher data rate
Single carrier transmission for the uplink
# Requirements for Broadband Wireless Access and its Solutions (Uplink)

- **Flexible available user rate**
  - High peak and average user rate in the Downlink
  - One cell reuse (no spreading)
  - Low PAPR
- **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

- **- Single Carrier TDMA with frequency domain equalizer**
- **- Dynamic Spectrum Control (DSC)**
  - Segmentation of radio resource in both time and freq. domain
  - DSC is applied in freq. Domain
- **Spectrum Commonality with OFDM**
Generation of Single Carrier Spectrum Compatible with OFDM
Single Carrier Waveform Compatible with OFDM

OFDM Transmission

- CP is a part of OFDM symbol
- Waveform of each symbol is regarded as periodic

Single Carrier Transmission

1 symbol

<table>
<thead>
<tr>
<th>$a_{n-2}$</th>
<th>$a_{n-1}$</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>...</th>
<th>$a_{n-2}$</th>
<th>$a_{n-1}$</th>
</tr>
</thead>
</table>

CP 1 frame

1 frame w/ Cyclic Prefix

- CP is a part of a frame
- Waveform of each frame is regarded as periodic
Dynamic Spectrum Control

Waveform \rightarrow \text{DFT} \rightarrow \text{Subcarrier Mapping} \rightarrow \text{IFFT} \rightarrow \text{CP insertion}

(a) System Bandwidth

(b) System Bandwidth

(c) System Bandwidth
**ISI Suppression and Signal Level Enhancement Effects**

**SINR Evaluation at the output of equalizer (FDE)**

\[
\text{SINR}_{eq} = \frac{S_{\text{desired}}}{S_{ISI} + N_{eq}} = \left[ \frac{S_{\text{desired}}}{S_{ISI}} \right]^{-1} + \left[ \frac{S_{\text{desired}}}{N_{eq}} \right]^{-1}
\]

![Graphs showing cumulative distribution for SINR gain, ISI suppression, and channel gain](image)

**SINR gain: 6 dB**  
**ISI suppression: 6 dB**  
**Channel gain: 6 dB**
BER Performances

Half Rate Transmission

Single Carrier

Block Size = 32
(Location adjustable single carrier)

10 dB

Block Size = 1

Block Size = 4

Single Carrier

Graph showing the BER Performances for different block sizes with DUR (dB) on the x-axis and BER on the y-axis.
Generalized Dynamic Spectrum Control

Resource Management + Adaptive Modulation For Any Scheme
Conclusions

- Development of DPC-OF/TDMA for the Downlink
  - Subcarrier level adaptive modulation with two stage punctured code
  - Large dynamic range data size is supportable
  - System throughput of more than 100 Mbit/s achievable
- Development of Single Carrier Transmission for the Uplink
  - Dynamic Spectrum Control (DSC)
    - OFDM compatible Spectrum
    - Effective in suppression of residual ISI in FDE
    - Effective in suppression of co-channel interference
  - Large dynamic range data size is supportable
    - By flexible spectrum mapping in addition to segmentation in time
    - DSC gives more flexibility in radio resource management