## Project
IEEE 802.20 Working Group on Mobile Broadband Wireless Access

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## Title
A Partial Proposal of Rotational OFDM Transmission Scheme

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## Source(s)
Toshinori Suzuki, Hiroyasu Ishikawa  
Yasuyuki Hatakawa  
KDDI R&D Laboratories, Inc.  
Hikarinooka 7-1, Yokosuka  
Kanagawa 239-0847  
Voice: +81-46-847-6350  
Fax: +81-46-847-0947  
Email: tn-suzuki@kddi.com  
hi-ishikawa@kddi.com  
ya-hatakawa@kddi.com

## Re: IEEE 802.20 Working Group Call for Proposals

## Abstract
As a partial proposal, this contribution discusses the rotational OFDM transmission scheme, which improves spectrum efficiency at the multi-path channel by making use of frequency diversity effect. This scheme can be applied to multi-carrier systems such as OFDMA.

## Purpose
To propose a new multi-carrier transmission technology which improves the performance of current multi-carrier based technologies. This technology can be applied or merged to complete system proposals based on TDD or FDD.

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## Patent Policy
A Partial Proposal of Rotational OFDM Transmission Scheme

IEEE 802.20 Plenary Meeting
Vancouver, Canada
November 14-18, 2005
1 Introduction

• In OFDMA, two types of transmissions are generally considered.
  – Block-wise transmission in localized mode
  – Non-consecutive (scattered) sub-carriers in distributed mode.

• OFDM has no frequency diversity effect originally, but it obtains frequency diversity effect by use of FEC
• Even in the distributed mode, the frequency diversity effect becomes low when the channel coding rate is high
• Rotational code-multiplexed OFDM with advanced receiver is proposed to compensate this weak point

Distributed mode makes use of frequency diversity, and is recommended for high speed users and/or delay sensitive traffic
2.1 OFDM Transmission without Walsh Code-Multiplexing

• A and B, are mapped onto 2 scattered sub-carriers, F1 and F2, respectively.
• Due to the frequency selective channel, sub-carrier powers are differently received.
• There is no frequency diversity effect at the modulation symbols.
• Some frequency diversity is derived by using the error correction scheme, which depends on the coding rate of FEC, though.
2.2 OFDM Transmission with Walsh Code-Multiplexing

- OFDM with code-multiplexing was expected to obtain the best diversity gain on frequency domain.
- Overall performance with FEC becomes worse than that of OFDM without code-multiplexing by inter-symbol (or inter-code) interference.

WCM means Walsh Code Multiplexing to operate the following formula for 2 dimensions.

\[
\begin{pmatrix}
  X \\
  Y
\end{pmatrix} = \begin{pmatrix}
  1 & 1 \\
  1 & -1
\end{pmatrix} \begin{pmatrix}
  A \\
  B
\end{pmatrix}
\]

(1)

In receiver side, MMSE (Minimum Mean Squared Error) equalization and despreader are used before demodulation.
3. Rotational OFDM Transmission

QPSK modulation and 2 dimensional code-multiplexing

Three features;

1. Rotational code-multiplexer (RCM)
   • By adjusting the rotation angle, optimum correlation is obtained between modulation symbols, which provides the best frequency diversity

2. Multi-dimensional demodulator (MD-DEM)
   • To avoid the ISI, multi-dimensional demodulator is used
   • Detecting the likelihood of the code-multiplexed symbol

3. Dual iteration decoder
   • Twin Turbo Decoder is appropriate for correlated signal produced by rotational OFDM
Rotational Code-Multiplexer (RCM) (I)

- RCM converts modulation symbols, A and B, into sub-carrier symbols X and Y, as follows.

\[
\begin{pmatrix} X \\ Y \end{pmatrix} = R_2 \begin{pmatrix} A \\ B \end{pmatrix} = \begin{pmatrix} \cos \theta_1 & \sin \theta_1 \\ -\sin \theta_1 & \cos \theta_1 \end{pmatrix} \begin{pmatrix} A \\ B \end{pmatrix}
\]  \hspace{1cm} (2)

- \( \theta_1 \): rotation angle
- \( \theta_1 = 0 \)  Normal OFDM without code--multiplexing
- \( \theta_1 = \pi/4 \)  Transmission performance is equivalent to that of Walsh code-multiplexed OFDM
- By adjusting the rotation angle, optimum correlation is obtained between modulation symbols A and B, which produces the best frequency diversity
- Rotational matrix can be expanded to higher dimensions as follows.

\[
R_4 = \begin{pmatrix} R_2 \cos \theta_2 & R_2 \sin \theta_2 \\ -R_2 \sin \theta_2 & R_2 \cos \theta_2 \end{pmatrix}
\]  \hspace{1cm} (3)
Rotational Code-Multiplexer (RCM) (II)

- QPSK symbol consists of I-phase component bit and Q-phase component bit
- I-phase bits are paid attention without loss of generality
- Let the I-phase bit of modulation symbol A be “a”, and that of symbol B be “b”
- Signal constellation constructed by I-phase channels on F1 and F2 is shown as follows

Assuming QPSK modulation
Rotational Code-Multiplexer (RCM) (III)

• At the constellation, the minimum distance between signals, such as the distance between “00” and “01”, dominates the transmission performance
• Rotating the constellation by $\frac{\pi}{4}$ ($\phi_1 = \frac{\pi}{4}$), makes the minimum distance stable against the Rayleigh fading, due to 2-branch (2-sub-carriers) diversity
• Diagonal distance, such as in-between “00” and “11”, tends to fluctuate by $\frac{\pi}{4}$ rotation, due to loss of 2-branch diversity
• Diagonal distance is longer than the minimum distance for 3dB, that drawback is not negligible with FEC
• Therefore, optimum rotation angle exists between 0 and $\frac{\pi}{4}$
Multi-Dimensional Demodulator (MD-DEM)

- Because of the frequency selectivity, signal constellation is generally distorted
- The conventional receiver uses MMSE equalization and despreading method
  - Brings inter-symbol (or inter-code) interference (ISI)
- To avoid the ISI, multi-dimensional demodulator is proposed, which detects the likelihood of the code-multiplexed symbol
Dual Iteration Decoder (Twin Turbo Decoder)

- MAP decoding assumes no correlation between inputted soft decisions as well as Viterbi decoding
- For correlated signals, their mutual information is discarded in conventional decoder
- In order to take it in, **Twin Turbo Decoder** is appropriate for rotational OFDM
- In addition to the conventional feedback loop for “Brief Propagation”, there is a 2nd feedback loop for “Brief Coupling”
- In this decoder, soft decisions are updated during Turbo decoding
## Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupied Bandwidth $W$</td>
<td>5.0 MHz</td>
</tr>
<tr>
<td>Sampling rate $t_s$ ($= 1 / W$)</td>
<td>0.2 µsec.</td>
</tr>
<tr>
<td># of sub-carriers</td>
<td>512</td>
</tr>
<tr>
<td>Data symbol duration</td>
<td>102.4 µsec.</td>
</tr>
<tr>
<td>CP duration</td>
<td>11.2 µsec.</td>
</tr>
<tr>
<td># of info. bits / frame (incl. tail bits)</td>
<td>1024 ($R = 1/2$), 3072 ($R = 3/4$)</td>
</tr>
<tr>
<td>Frame length</td>
<td>1 OFDM symbol ($R = 1/2$ &amp; 16QAM), 2 OFDM symbols ($R = 1/2$ &amp; QPSK, $R = 3/4$ &amp; 16QAM), 4 OFDM symbols ($R = 3/4$ &amp; QPSK)</td>
</tr>
<tr>
<td>Channel coding</td>
<td>Turbo code ($K = 4$)</td>
</tr>
<tr>
<td>Coding rate ($= R$)</td>
<td>1/2, 3/4</td>
</tr>
<tr>
<td>Decoding algorithm</td>
<td>Max Log-MAP / 8 iterations</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM</td>
</tr>
<tr>
<td>Rotation dimension ($= D$)</td>
<td>2, 4</td>
</tr>
<tr>
<td>Rotation angle for rotational OFDM</td>
<td>$\theta_1, \theta_2 = 0.3 \sim 0.7 \pi/4$</td>
</tr>
<tr>
<td>Channel model</td>
<td>Pedestrian B (3 km/h), Vehicular B (30 km/h) [6]</td>
</tr>
<tr>
<td># of receiving antenna</td>
<td>1</td>
</tr>
<tr>
<td>Channel estimation</td>
<td>Ideal</td>
</tr>
</tbody>
</table>

Nov. 14, 2005

Suzuki, Ishikawa, Hatakawa, KDDI R&D Laboratories
Simulation Results (I)

Frame Error Rates (QPSK in Pedestrian B channel)
Simulation Results (II)

Frame Error Rates (QPSK in Vehicular B channel)
Simulation Results (III)

Frame Error Rates (16QAM in Pedestrian B channel)

Plot showing frame error rates for different modulation schemes and rates, with the x-axis representing the average $E_s/N_0$ in dB, and the y-axis representing frame error rate.
Simulation Results (IV)

Frame Error Rates (16QAM in Vehicular B channel)

- OFDM w/o CM
- R-OFDM (D = 2)
- R-OFDM (D = 4)
Conclusion

• Rotational OFDM transmission scheme for distributed mode was proposed
• By using the RCM (Rotational Code Multiplexing) and advanced detection, frequency diversity gain increases, especially in case of higher channel coding rate
• It should also be noted that the RCM is a parameterized function which contains normal OFDM scheme with no rotation angle
• Spectrum efficiency can be improved for distributed mode in OFDMA