Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** **Document # C802.20-05/70**
Title	**A Partial Proposal of Rotational OFDM Transmission Scheme**
Date Submitted	**2005-11-14**
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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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Release	
Patent Policy	

A Partial Proposal of Rotational OFDM Transmission Scheme

IEEE 802.20 Plenary Meeting

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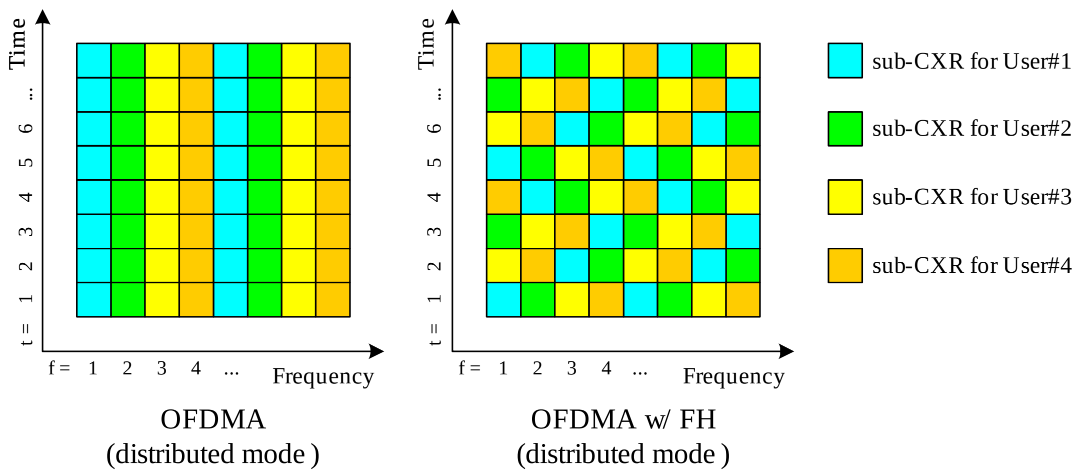
1 Introduction

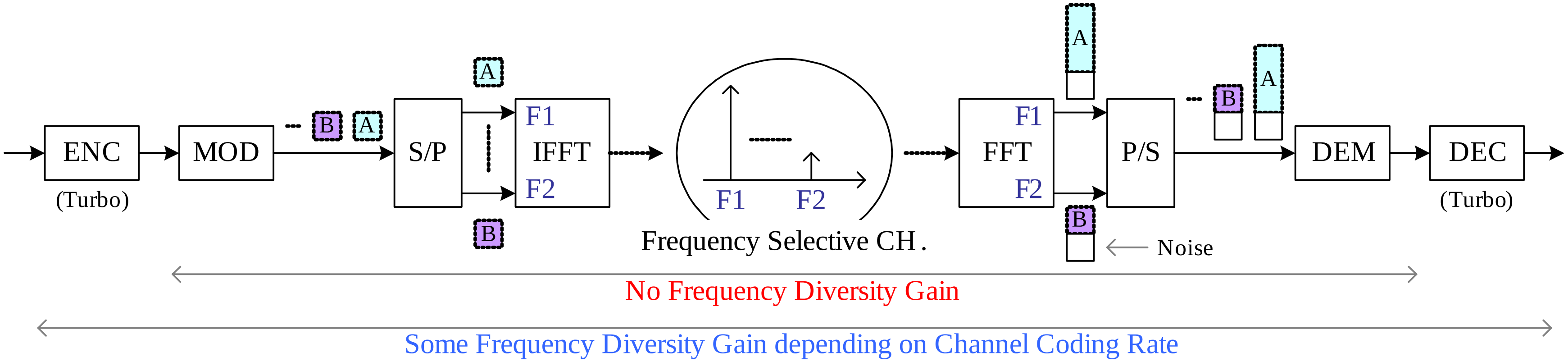
- **In OFDMA, two types of transmissions are generally considered.**
  - **Block-wise transmission in localized mode**
  - **Non-consecutive (scattered) sub-carriers in distributed mode.**



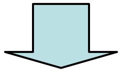
Distributed mode makes use of frequency diversity, and is recommended for high speed users and/or delay sensitive traffic

- **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**

2.1 OFDM Transmission without Walsh Code-Multiplexing

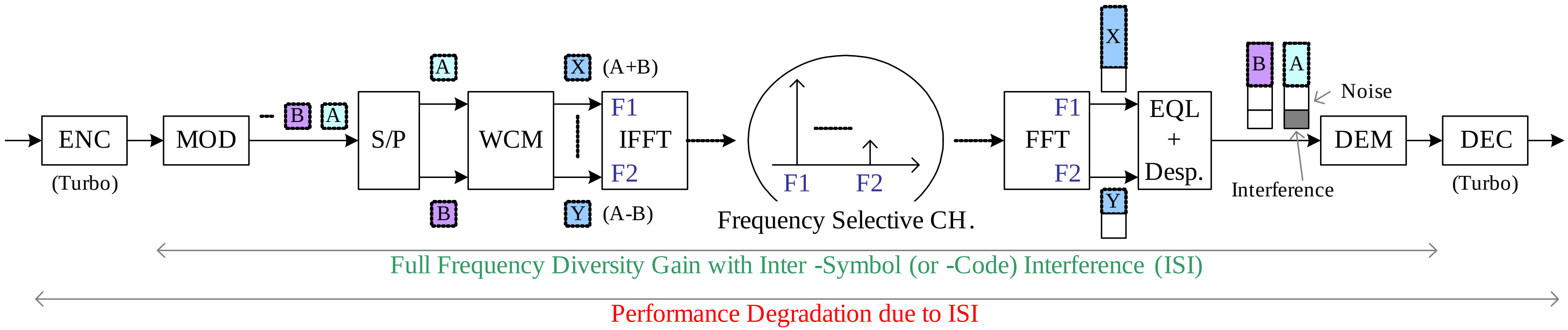


- **A and B, are mapped onto 2 scattered sub-carriers, F1 and F2, respectively.**
- **Due to the frequency selective channel, sub-carrier powers are differently received.**



- **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



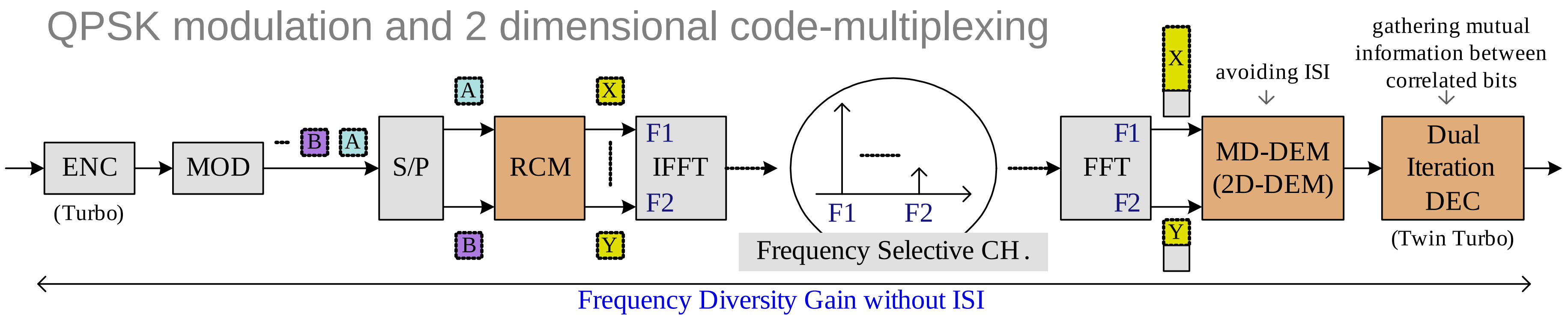
- OFDM with code-multiplexing was expected to obtain the best diversity gain on frequency domain.
- Overall performance with FEC becomes worse than that of OFDM without code-multiplexing by inter-symbol (or inter-code) interference

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

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} A \\ B \end{pmatrix} \qquad (1)$$

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

3. Rotational OFDM Transmission



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.**

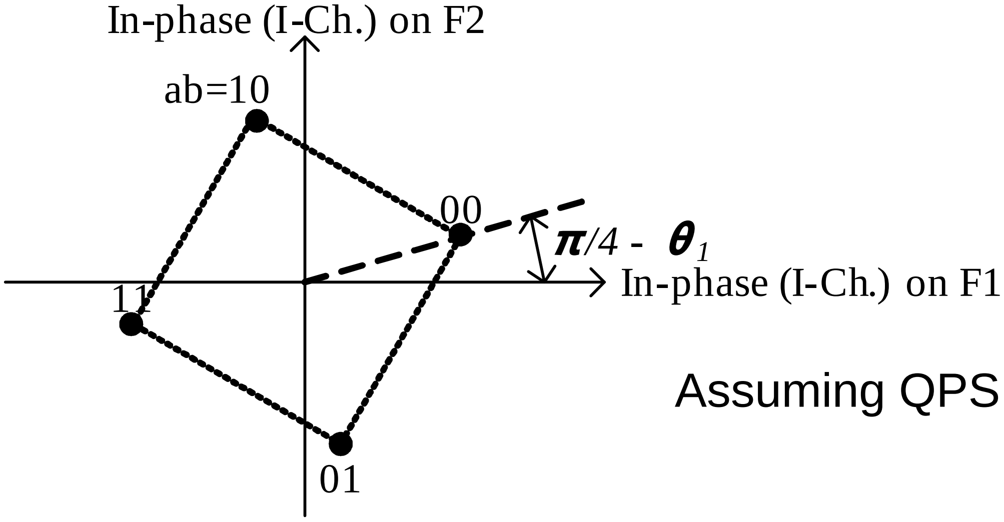
$$\begin{pmatrix} X \\ Y \end{pmatrix} = \mathbf{R}_2 \begin{pmatrix} A \\ B \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & \sin\theta_1 \\ -\sin\theta_1 & \cos\theta_1 \end{pmatrix} \begin{pmatrix} A \\ B \end{pmatrix} \qquad \textbf{(2)}$$

- **θ_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.**

$$\mathbf{R}_4 = \begin{pmatrix} \mathbf{R}_2\cos\theta_2 & \mathbf{R}_2\sin\theta_2 \\ -\mathbf{R}_2\sin\theta_2 & \mathbf{R}_2\cos\theta_2 \end{pmatrix} \qquad \textbf{(3)}$$

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

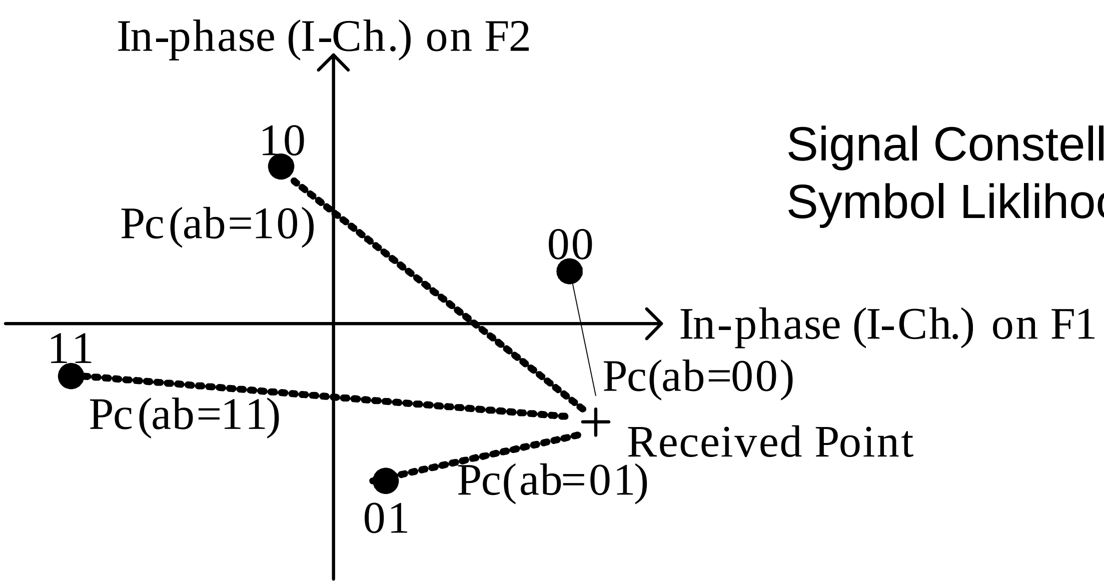
Rotational Code-Multiplexer (RCM) (III)

- At the constellation, the minimum distance between signals, such as the distance between “00” and “01”, dominates the transmission performance
- Rotating the constellation by $\pi/4$ ($\theta_1 = \pi/4$), 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 $\pi/4$ 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 $\pi/4$

Multi-Dimensional Demodulator (MD-DEM)

- Because of the frequency selectivity, signal constellation is generally distorted
- The conventional receiver uses MMSE equalization and despreading method

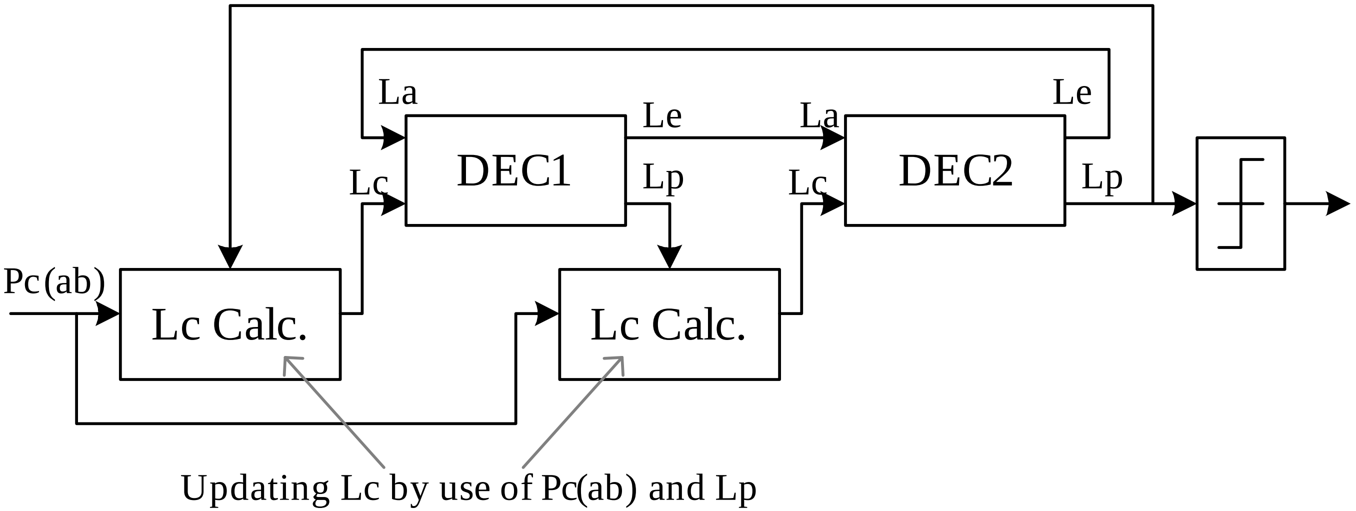
  → brings inter-symbol (or inter-code) interference (ISI)
- To avoid the ISI, multi-dimensional demodulator is proposed, which detects the likelihood of the code-multiplexed symbol



Signal Constellation and the Symbol Liklihood at Receiver Side

Dual Iteration Decoder (Twin Turbo Decoder)

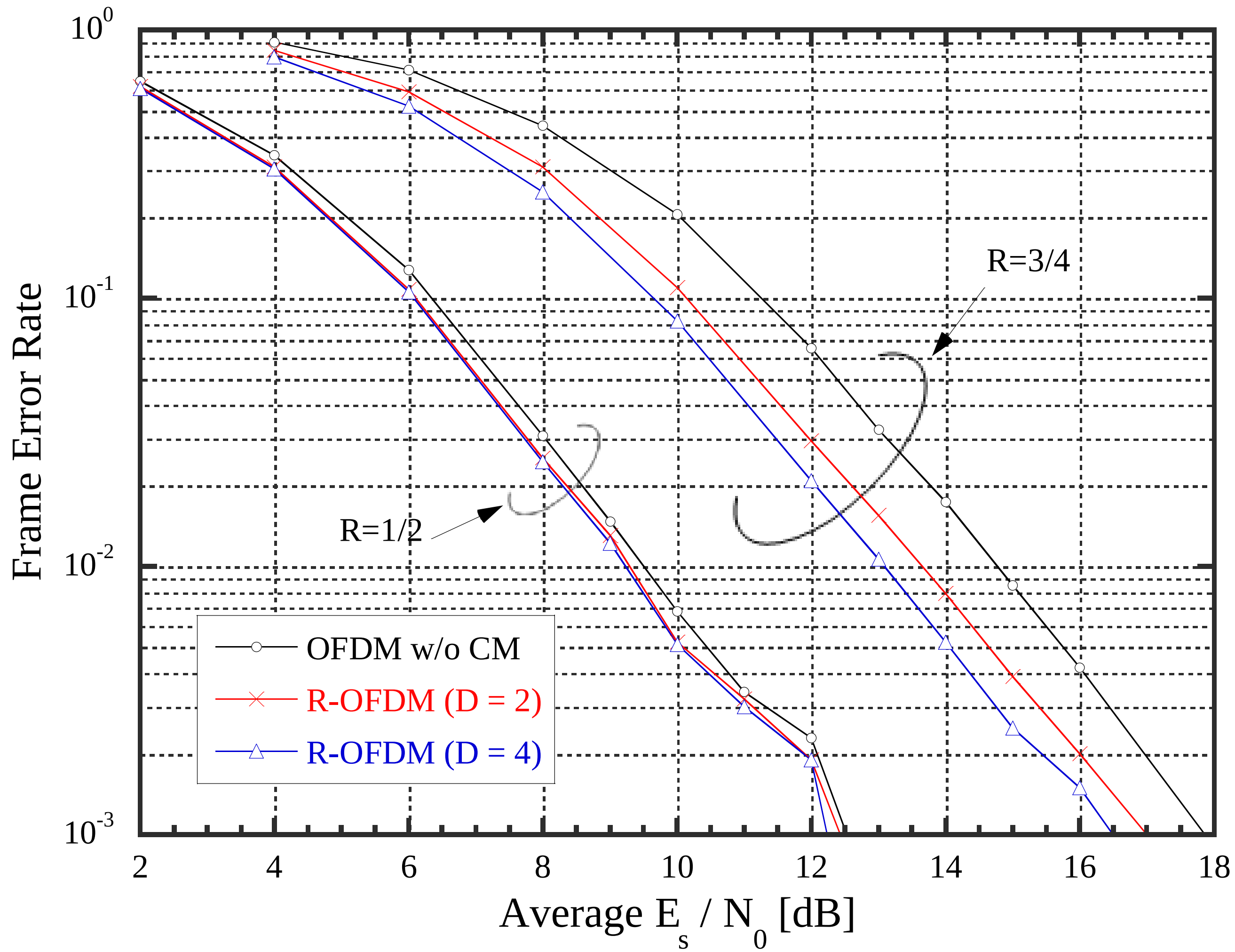
- **MAP decoding assumes no correlation between inputted soft decisions as well as Viterbi decoding**
- **For correlated signals, their mutual information is discarded in conventional decoder**
- **In order to take it in, Twin Turbo Decoder is appropriate for rotational OFDM**
- **In addition to the 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

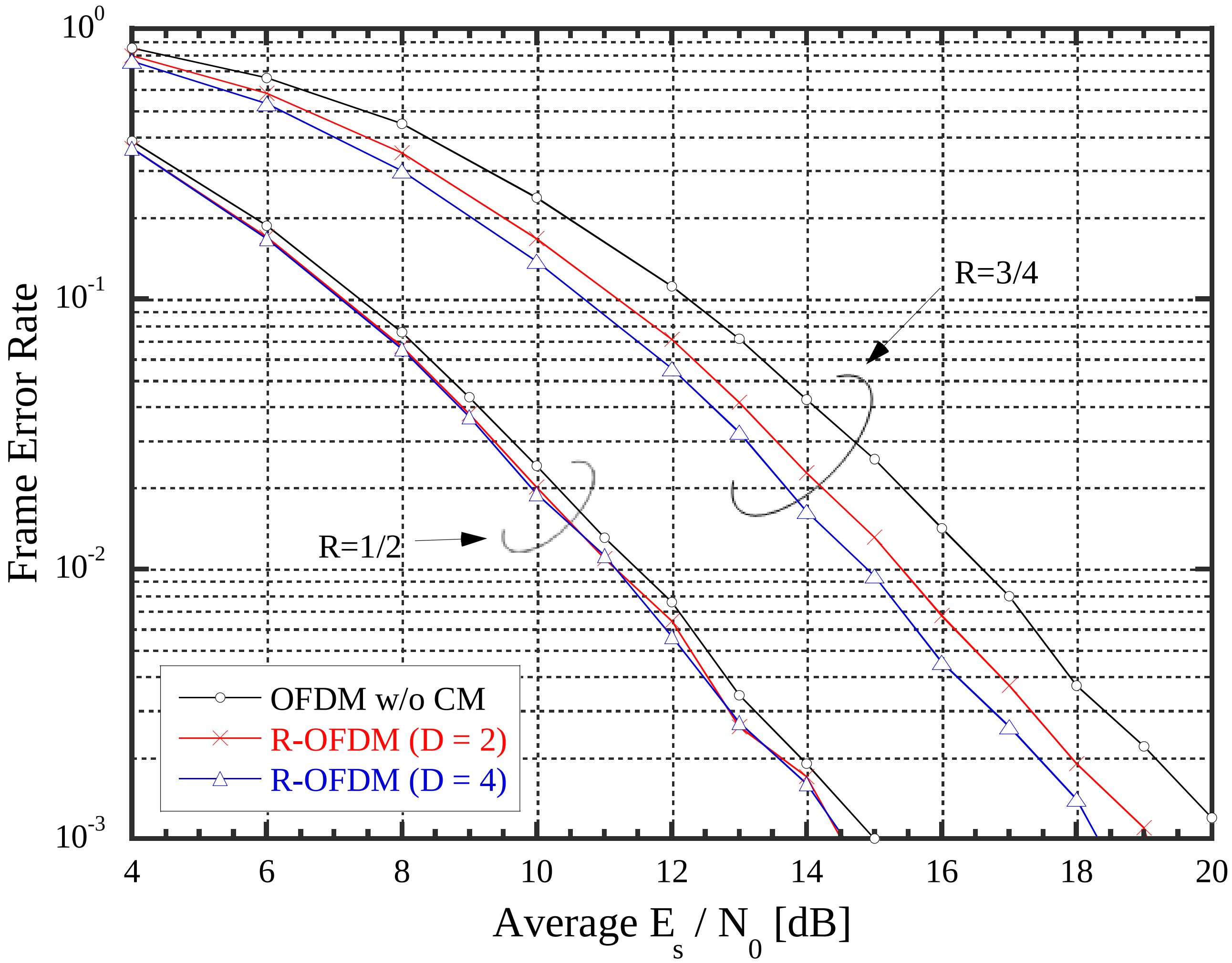
Occupied Bandwidth W	5.0 MHz
Sampling rate t_s (= 1 / W)	0.2 μsec.
# of sub-carriers	512
Data symbol duration	102.4 μsec.
CP duration	11.2 μsec.
# of info.bits / frame (incl. tail bits)	1024 (R = 1/2), 3072 (R = 3/4)
Frame length	1 OFDM symbol (R = 1/2 & 16QAM), 2 OFDM symbols (R = 1/2 & QPSK, R = 3/4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

Simulation Results (I)



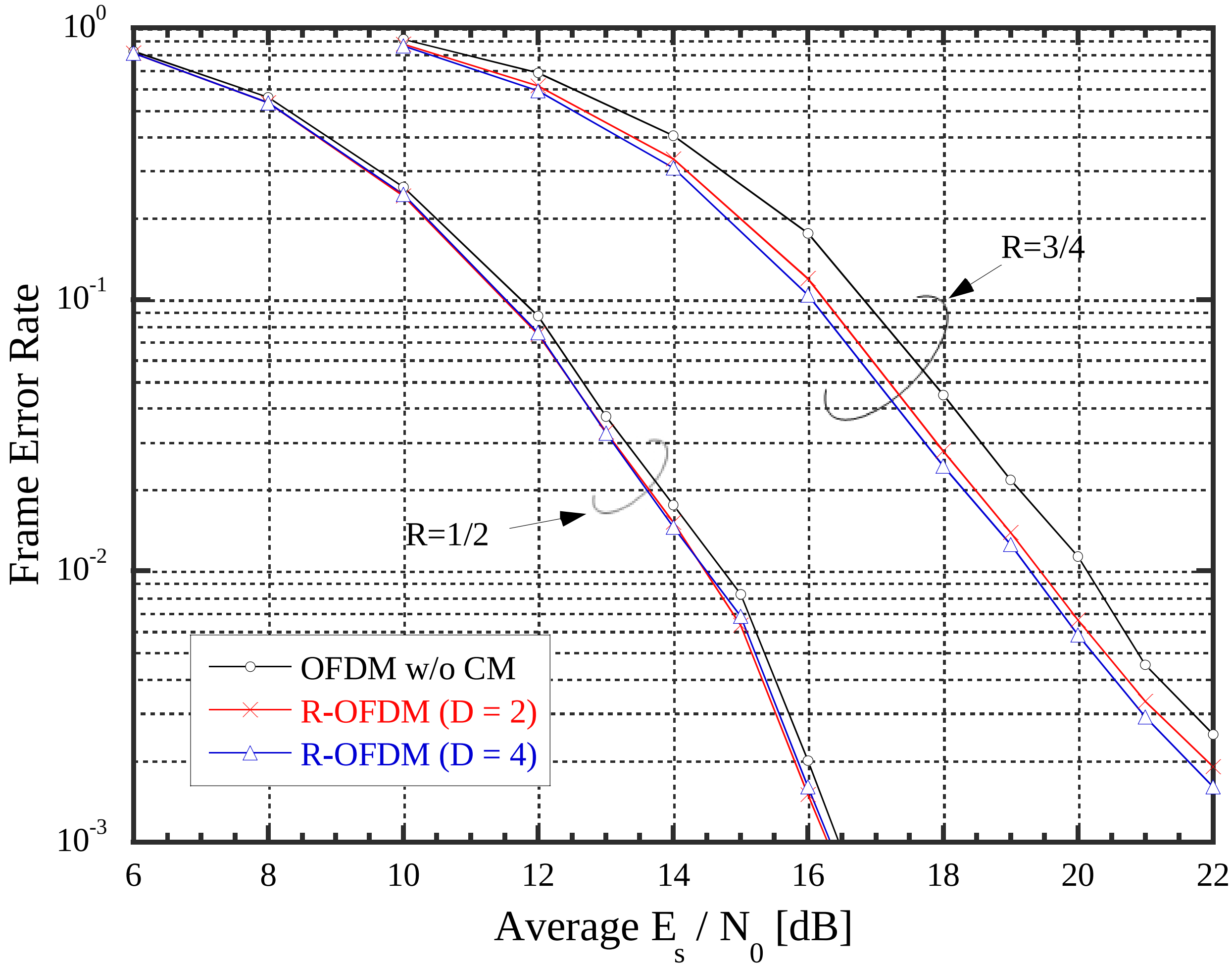
Frame Error Rates (QPSK in Pedestrian B channel)

Simulation Results (II)



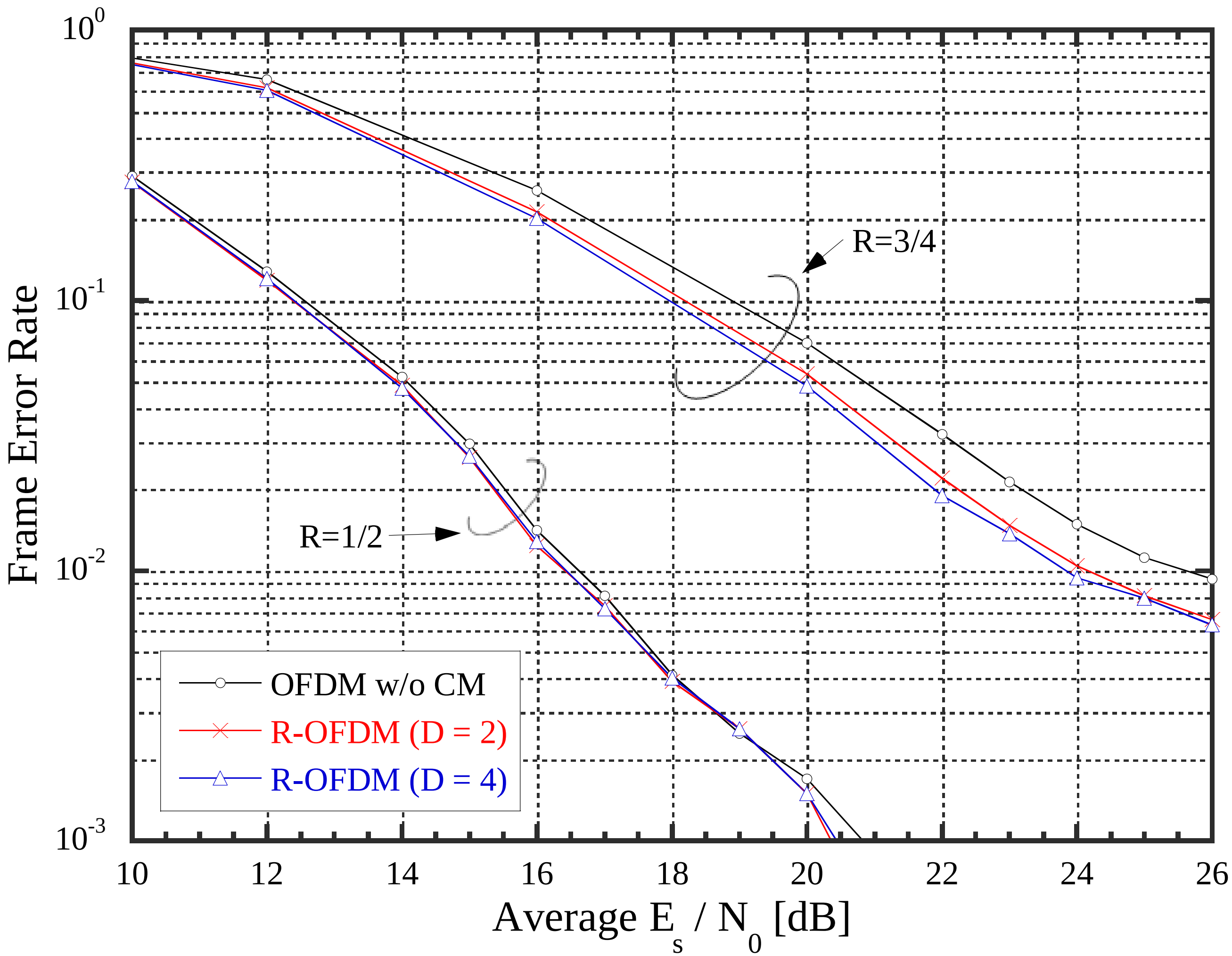
Frame Error Rates (QPSK in Vehicular B channel)

Simulation Results (III)



Frame Error Rates (16QAM in Pedestrian B channel)

Simulation Results (IV)



Frame Error Rates (16QAM in Vehicular B channel)

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