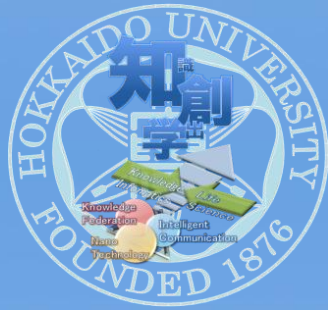




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Dynamic Wordlength Calibration for Energy Efficient FFT Processors in Wireless OFDM Systems

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Introduction - Background

□ OFDM Technique

- IEEE802.11a/g/n, WiMAX, and Digital Audio/Video Broadcasting.
- Limited Battery for Portable

□ Low Power Solutions in Hardware

- Pipeline Architecture
- Voltage Scaling
- Dynamic Wordlength

□ Wordlength in Digital Signal Processing

- System Performance
- Hardware Cost

Introduction - Approach

□ Dynamic Wordlength Technique

- Decrease Switching Activities of Unnecessary Bits
- Gated Clock Design

□ Operation Conditions

- Various Modulation Schemes

□ Rounding Error Detection

- Output Binary Data of Channel Decoder
- Hamming Distance

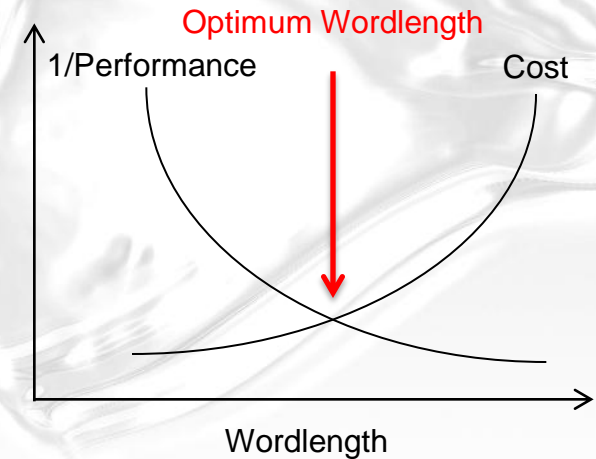
□ Link Adaptation

- Automatic rate fallback (ARF)

Optimum Wordlength

□ Optimum Wordlength

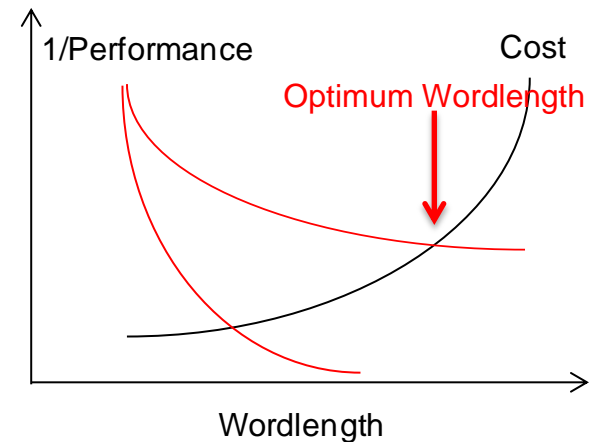
- Maximize Performance
- Minimize Hardware Cost



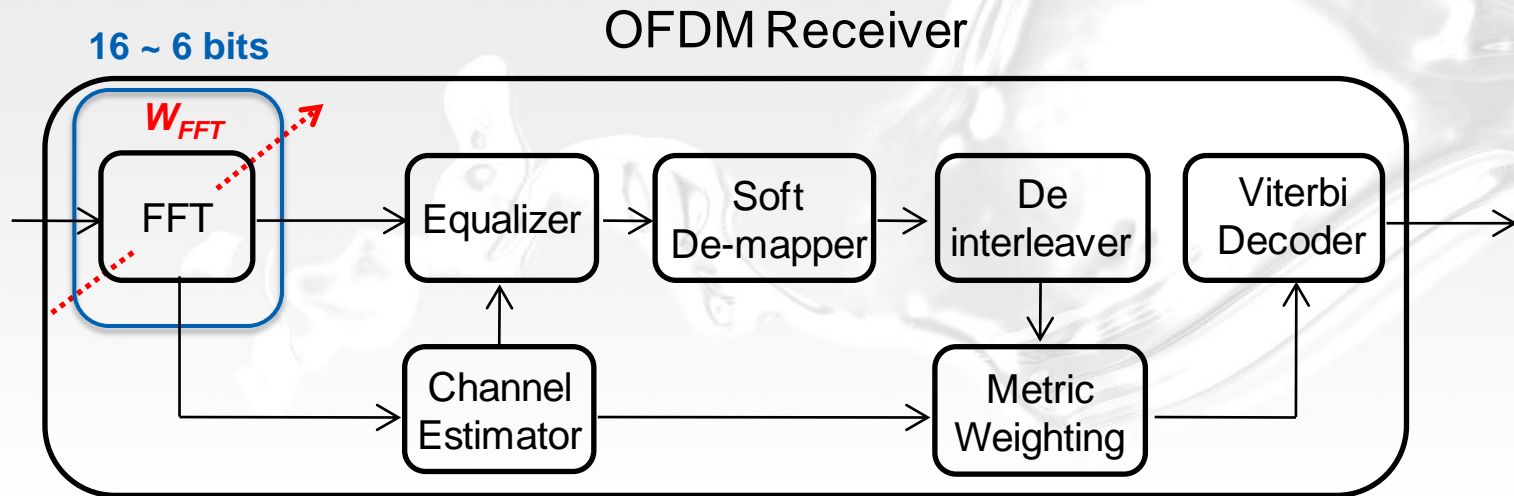
□ Various Environments

- Operation Conditions
- Channel Conditions

Good Environments



Concept of Dynamic Wordlength



- ❑ 16-bit wordlength is used for the FFT processors in wireless OFDM receiver.
- ❑ Dynamic wordlength FFT processor is dynamically determined according to the various environments.

Automatic Rate Fallback

Mode	Modulation	Code Rate	Data Rate
1, 2	BPSK	1/2 and 3/4	3 and 9 Mbps
3, 4	QPSK	1/2 and 3/4	12 and 18 Mbps
5, 6	16-QAM	1/2 and 3/4	24 and 36 Mbps
7, 8	64-QAM	2/3 and 3/4	48 and 54 Mbps

❑ Various Modulation and Code Rate Schemes

- Providing data rates up to 54 Mbps in IEEE802.11a standard.

❑ Frame Check Sequency (FCS) in Frame Trailer of MAC Protocol

- Packet Error Detection.

❑ Automatic Rate Fallback (ARF)

- Eight PHY modes are adapted according to packet reception.
- ARF is commonly adopted in commercial products.

Operation Conditions

Mode	Modulation	Dynamic Wordlength Range
1, 2, 3, 4	BPSK and QPSK	12, 10, 9, 8, 6
5, 6	16-QAM	12, 10, 9, 8
7, 8	64-QAM	16, 14, 12, 10

❑ Wordlength in Wireless Communication System

- Sufficient wordlength is required for the worst operation condition.

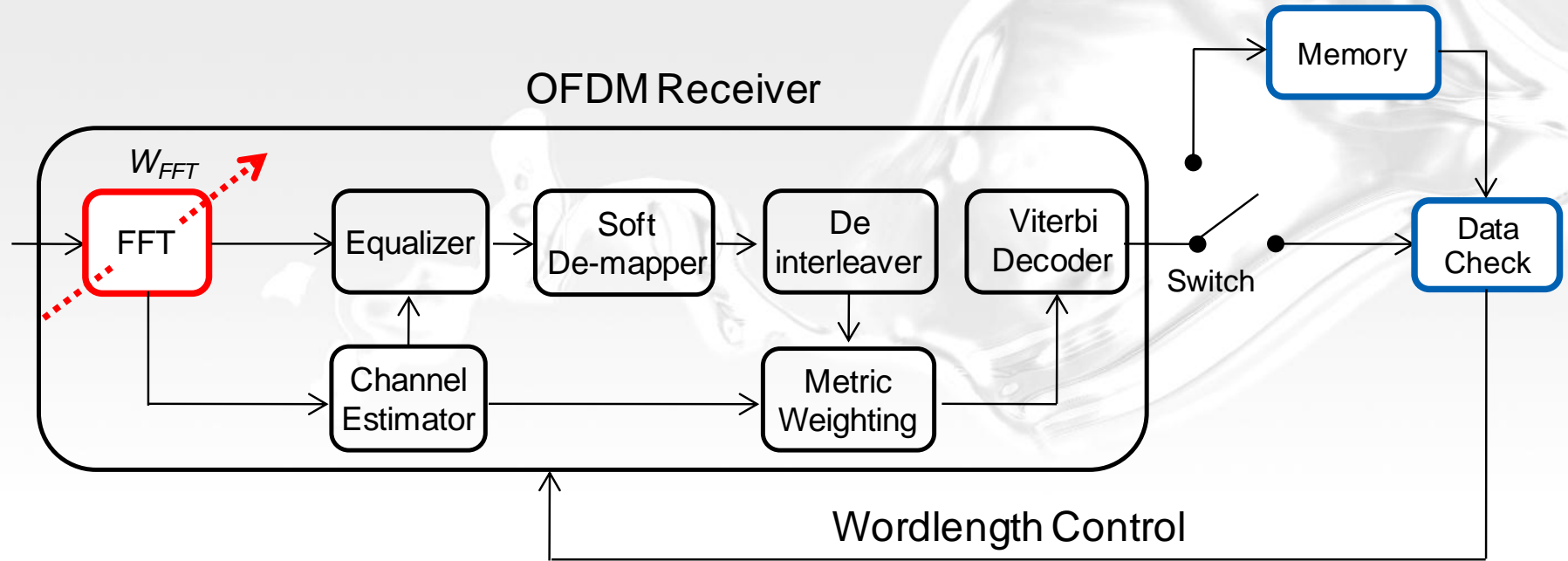
❑ Determined Wordlength of FFT Processor

- The number of information bits in a symbol is increased for higher schemes.
- The required precision is depending on the modulation schemes.

❑ Dynamic Wordlength Range

- Define different dynamic wordlength range for the eight PHY modes.

Proposed System



❑ Memory Block

- Hold the output binary data with the maximum wordlength.

❑ Data Check Block

- Calculate hamming distance of each wordlength for the maximum wordlength.
- Determine an optimum wordlength according to zero distance.

Rounding Error Detection

Wordlengths	Output binary data of channel decoding	Hamming Distance
16	1 0 1 0 0 0 1 0 0 1 0 0 1 ... 0 1 0 1 1 0	-
14	1 0 1 0 0 0 1 0 0 1 0 0 1 ... 0 1 0 1 1 0	0
12	1 0 1 0 0 0 1 0 0 1 0 0 1 ... 0 1 0 1 1 0	0
...
9	1 0 1 0 0 0 1 0 0 1 0 0 1 ... 0 1 0 1 1 0	0
8	1 0 1 0 0 1 1 0 0 1 1 0 1 ... 1 0 0 1 1 0	4
6	1 1 1 1 0 1 1 0 0 1 1 0 1 ... 1 0 0 1 1 1	7

❑ Zero Distance

- The de-mapper signal detection absorbs these rounding error by decreasing wordlength of FFT processors.

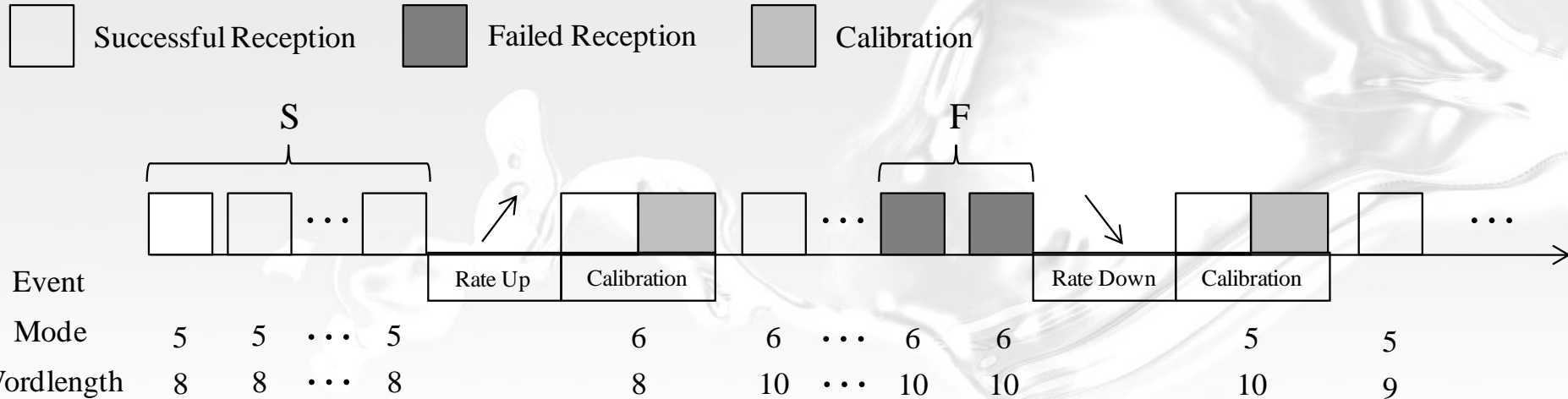
❑ Non Zero Distance

- It assumed that a bit error happen due to rounding errors.

❑ Hamming Distance

- Minimum wordlength having a zero value in hamming distance.

Wordlength Control with ARF



□ ARF

- Rate Up with **S** consecutive successful reception.
- Rate Down with **F** consecutive failed reception.

□ The Proposed Method

- Calibration method is executed after the ARF events.
- The determined wordlength is performed for the next packet in the changed mode scheme.
- The first symbol at a transmitted packet is used for detecting rounding errors.

Evaluation - Simulation Parameters

Multipath Channel Model	HIPERLAN/2 Model A (RMS delay spread 50 ns)
Doppler Frequency	50Hz
Number of Data Carriers	48
Number of Data Symbols	10
Guard Interval	0.8 μ s
FFT Size	64
Error Correcting	Convolutional Code (R = 1/2)
Constraint Length	K=7
Symbol Timing	Ideal
S / F	49 / 2
Packet Count	10,000

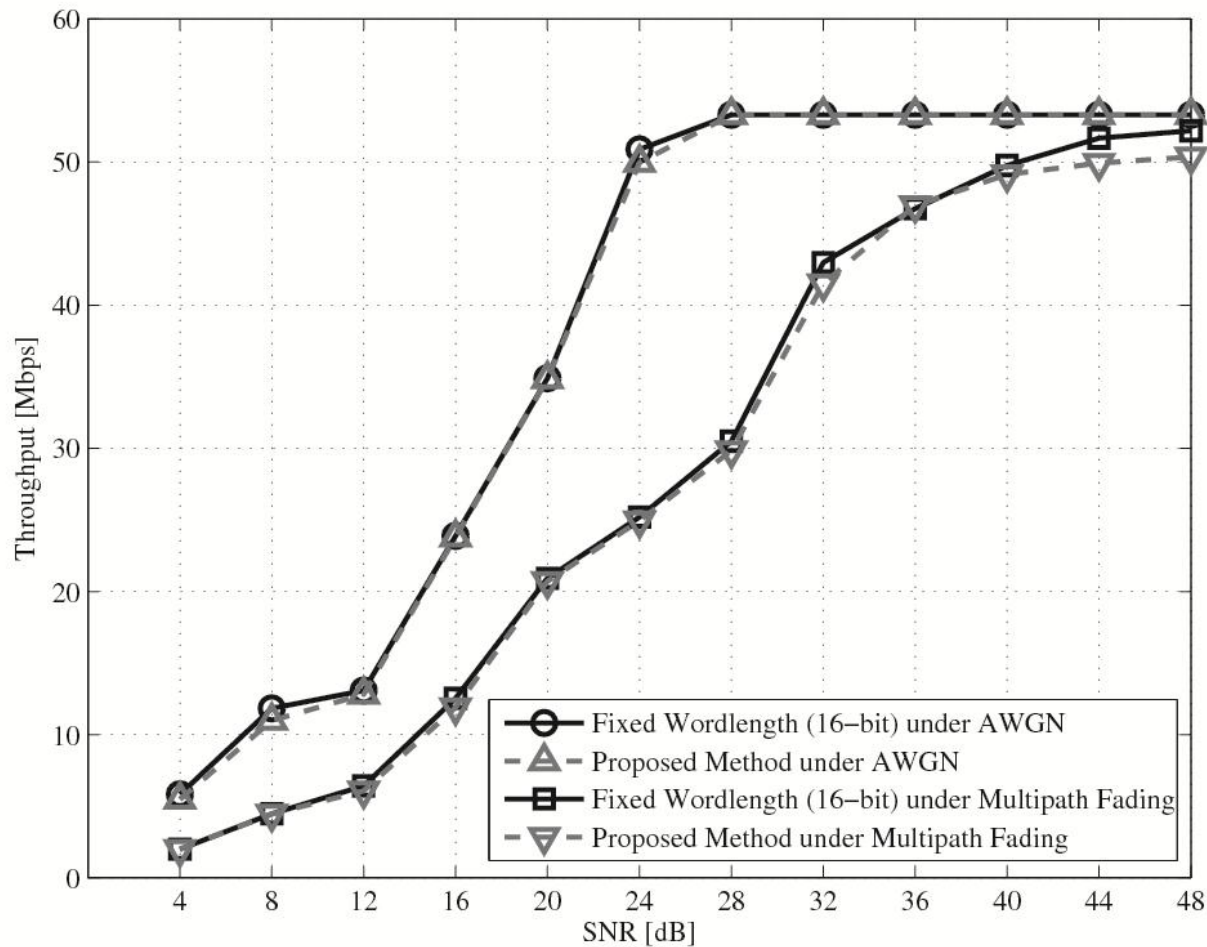
Evaluation - Synthesis Results

Technology	CMOS 90-nm
Clock Frequency	160 MHz
No. of Logic Gates	34,410
Maximum Power Dissipation (mW)	16.04

Wordlength	16	14	12	10	9	8	6
Power (mW)	16.04	14.85	13.73	12.5	11.89	11.21	9.88
Ratio	1	0.926	0.856	0.779	0.741	0.699	0.616

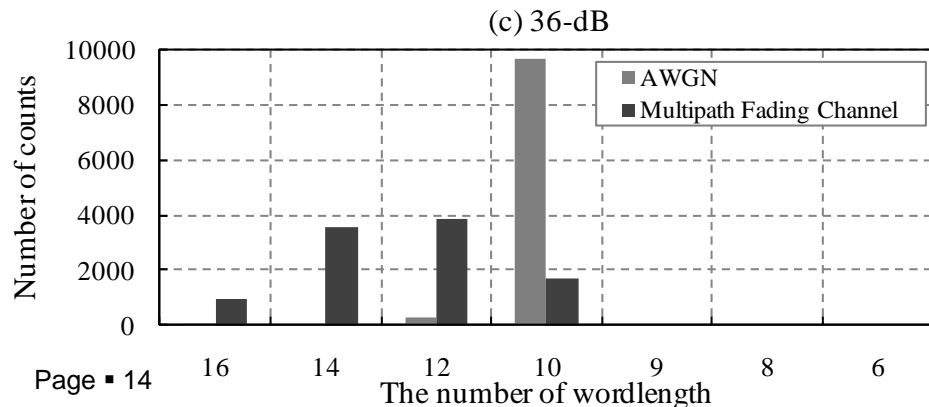
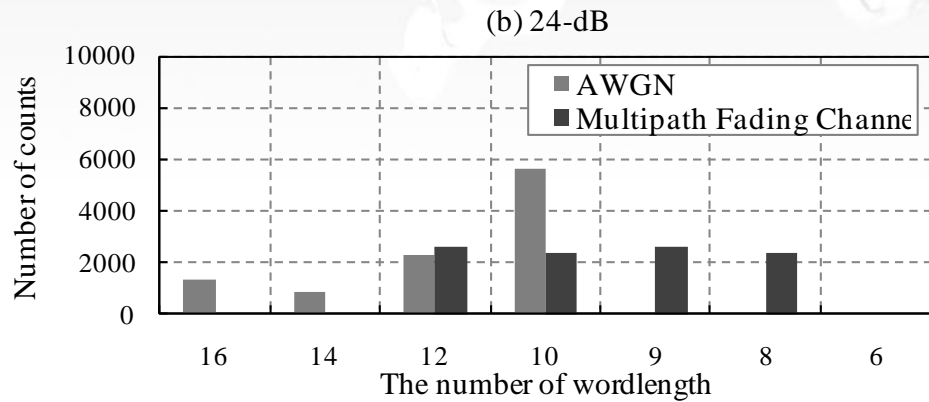
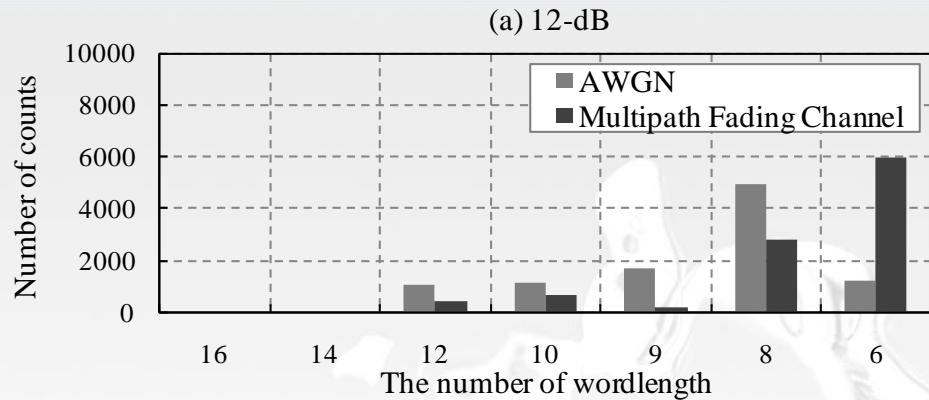
- ❑ Radix-2 single delay feedback (R2SDF) architecture have designed by using Verilog HDL in RTL description.
- ❑ The circuits were synthesized with 1.0 V supply voltage and 160 Mhz clock frequency in 90-nm CMOS standard cell library.

Evaluation - Throughput



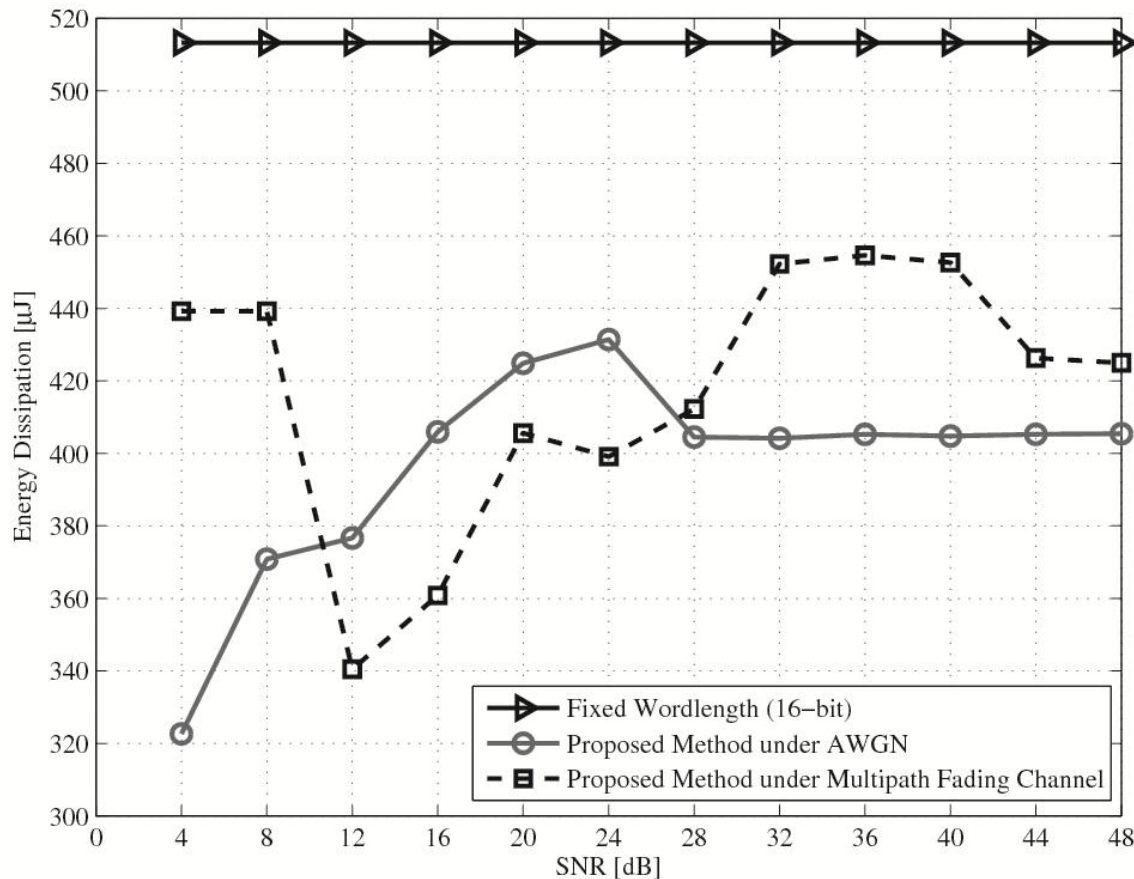
$$\text{Throughput} = (1 - \text{PER}) \times \text{DataRate}(M)$$

Evaluation - The Selected Wordlength



- ❑ The selected wordlengths of FFT processor for AWGN and multipath fading channel environments.
- ❑ In (a) 12-dB, the proposed FFT processor was performed by 12 to 6-bit wordlengths in the defined dynamic wordlength range with modulation schemes.
- ❑ In (b) 24-dB and (c) 36-dB, larger wordlengths were selected with higher modulation schemes for the efficient throughput up to 54 Mbps under AWGN channel.

Evaluation - Energy Dissipation



$$E = \frac{1}{T} \sum_{t=1}^T E_{(t)}$$

$$E_{(t)} = \begin{cases} \text{W / O Calibration} \\ P[W_{D(t)}] \cdot N_{sym} \cdot T_{sym} \\ \text{With Calibration} \\ P[W_{D(t)}] \cdot N_{sym} \cdot T_{sym} + P[C_{(t)}] \cdot T_{sym} \end{cases}$$

T : Total packet counts

$P_{[WD(t)]}$: Power of determining wordlength at t

N_{sym} : Number of symbol

T_{sym} : Time of symbol

$P_{[C(t)]}$: Power of operating the calibration method

Energy reduction under AWGN and Multipath Fading Channel

- Maximum of 37.1 % and 33.7 %
- Average of 22.7 % and 18.7 %

Conclusion

□ Dynamic Wordlength Calibration Method

- Dynamic Wordlength Range - Operation Conditions
- Hamming Distance - Rounding Error Detection
- Applying ARF - Link Adaptation

□ Evaluation

- Energy Reduction - 37.1 % and 33.7 %
- Efficient Throughput

□ Future Work

- Multiple Dynamic Wordlengths
- MIMO-OFDM System



Thank you