Subcarrier Index Coordinate Expression (SICE): An Ultra-low-power OFDM-Compatible Wireless Communications Scheme Tailored for Internet of Things

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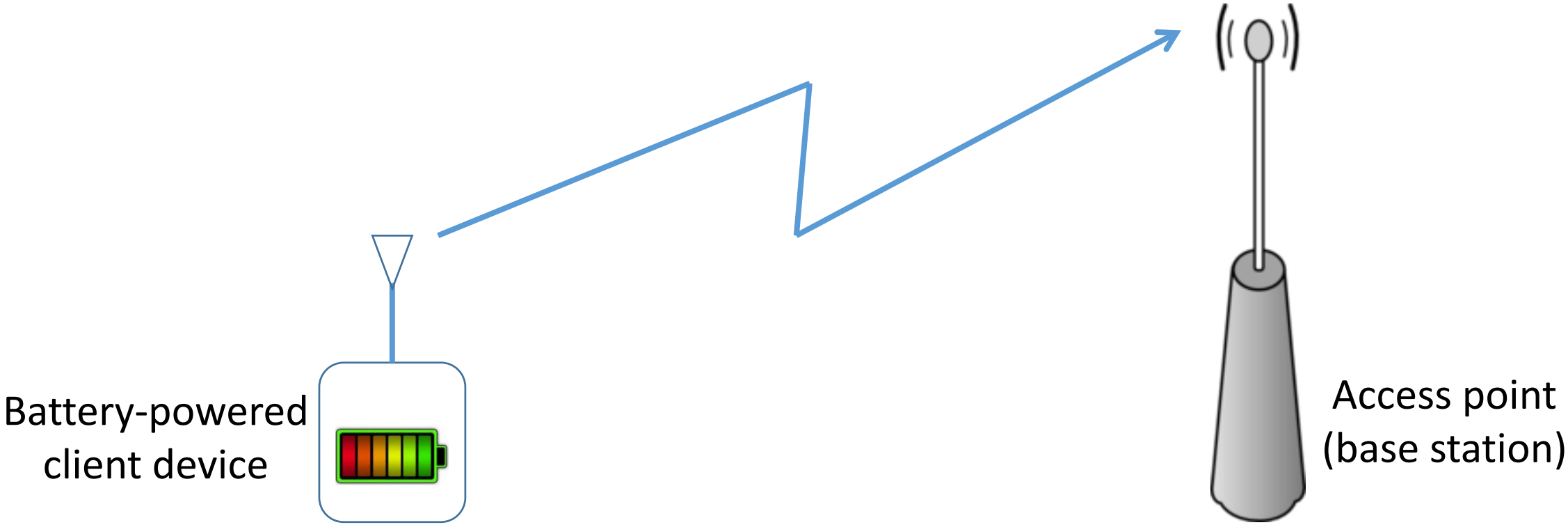
Outline

- Motivation and objective
- The Proposed SICE approach
- Performance evaluation

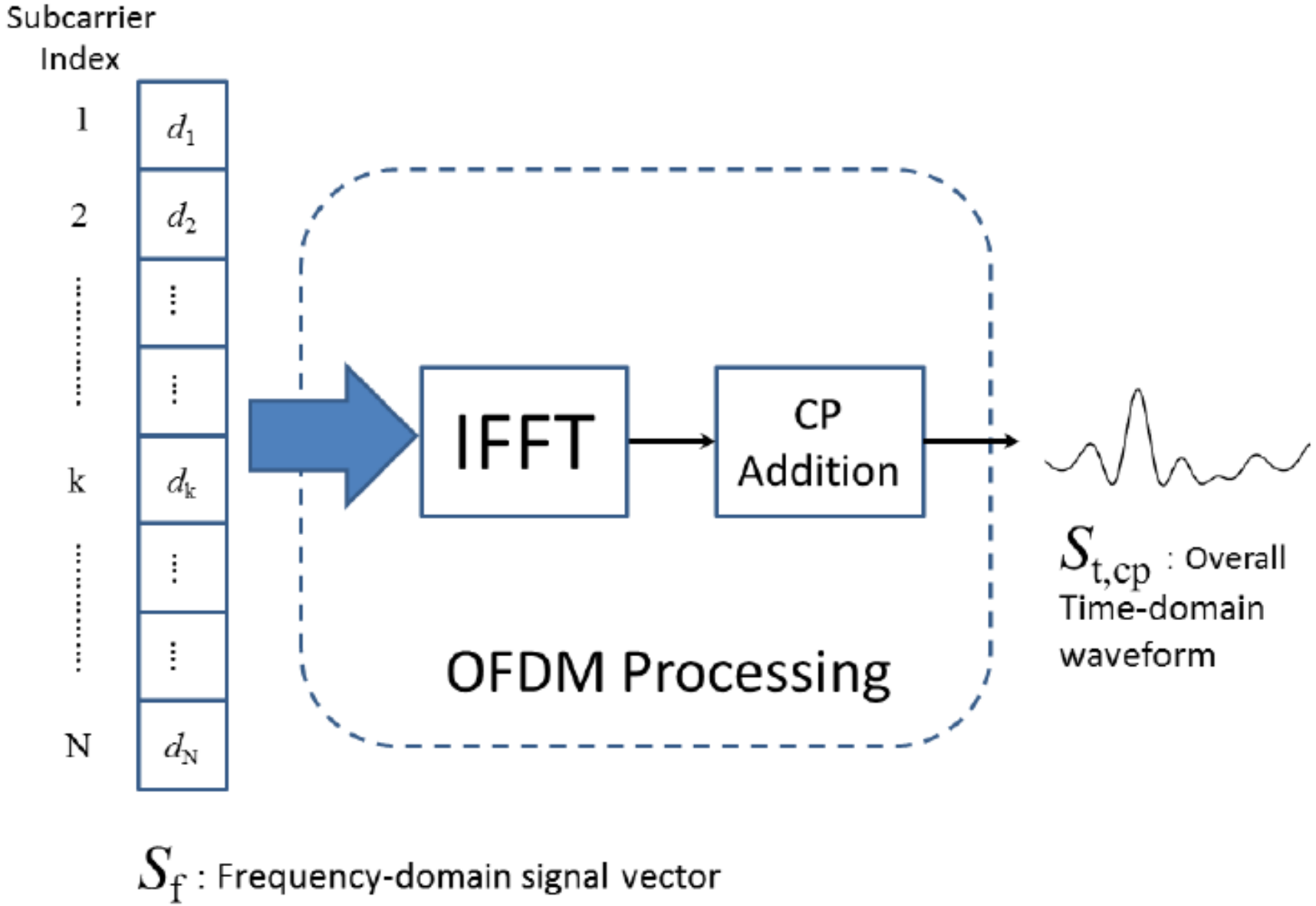
Motivation and Objective

We are interested in developing an **OFDM-compatible** physical-layer scheme for uplink communications of wireless IoT devices, which would **achieve high efficiency in power usage** while **reducing hardware cost**



A Quick Overview of Orthogonal Frequency Division Multiplexing (OFDM)

- OFDM is widely used air nterface for networks such as Wi-Fi (IEEE 802.11) and 4G cellular networks (LTE)
- OFDM achieves high data rate by sending a large number of low-rate data symbols simultaneously on subcarriers with different frequencies

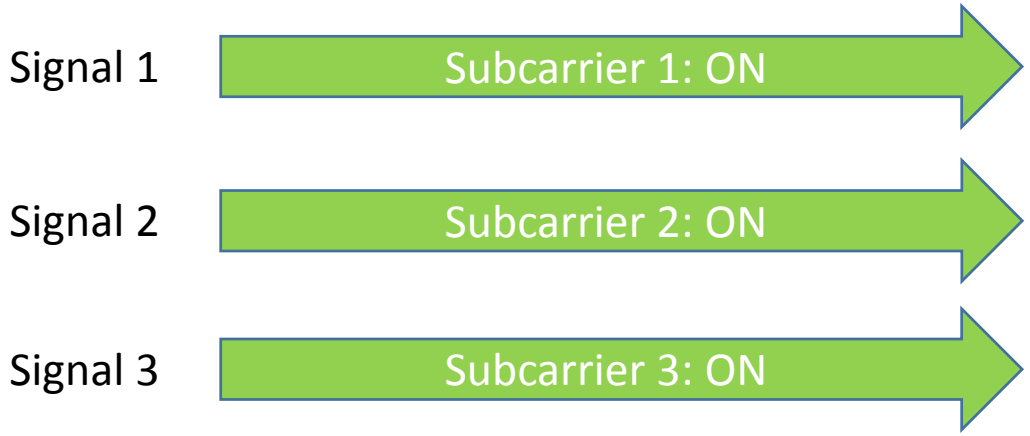


Two Issues with OFDM for IoT Communication

1. For low-bandwidth IoT applications, simultaneous use of **many subcarriers** *is power inefficient*
2. OFDM may experience a *large* **peak to average power ratio (PAPR)**
   - With OFDM the resultant time-domain waveform is the sum of N sinusoidal waveforms. It may have a large peak in wave construction
   - A large PAPR is undesirable due to signal distortion caused by non-linearity of the power amplifier (often IoT devices can only afford inexpensive, power-efficient amplifiers)

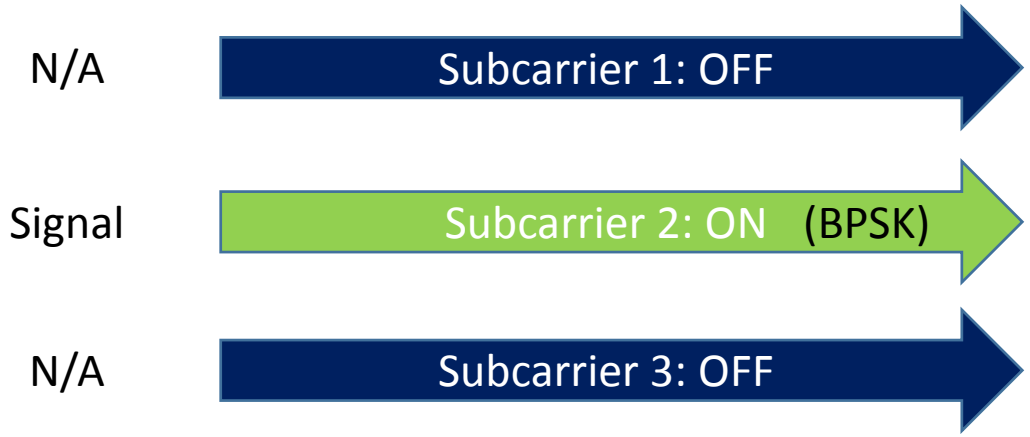
Proposed Solution: Subcarrier Index Coordinate Expression (SICE)

Instead of:



Information representation is solely based on **WHAT signals** are being transmitted on the subcarriers

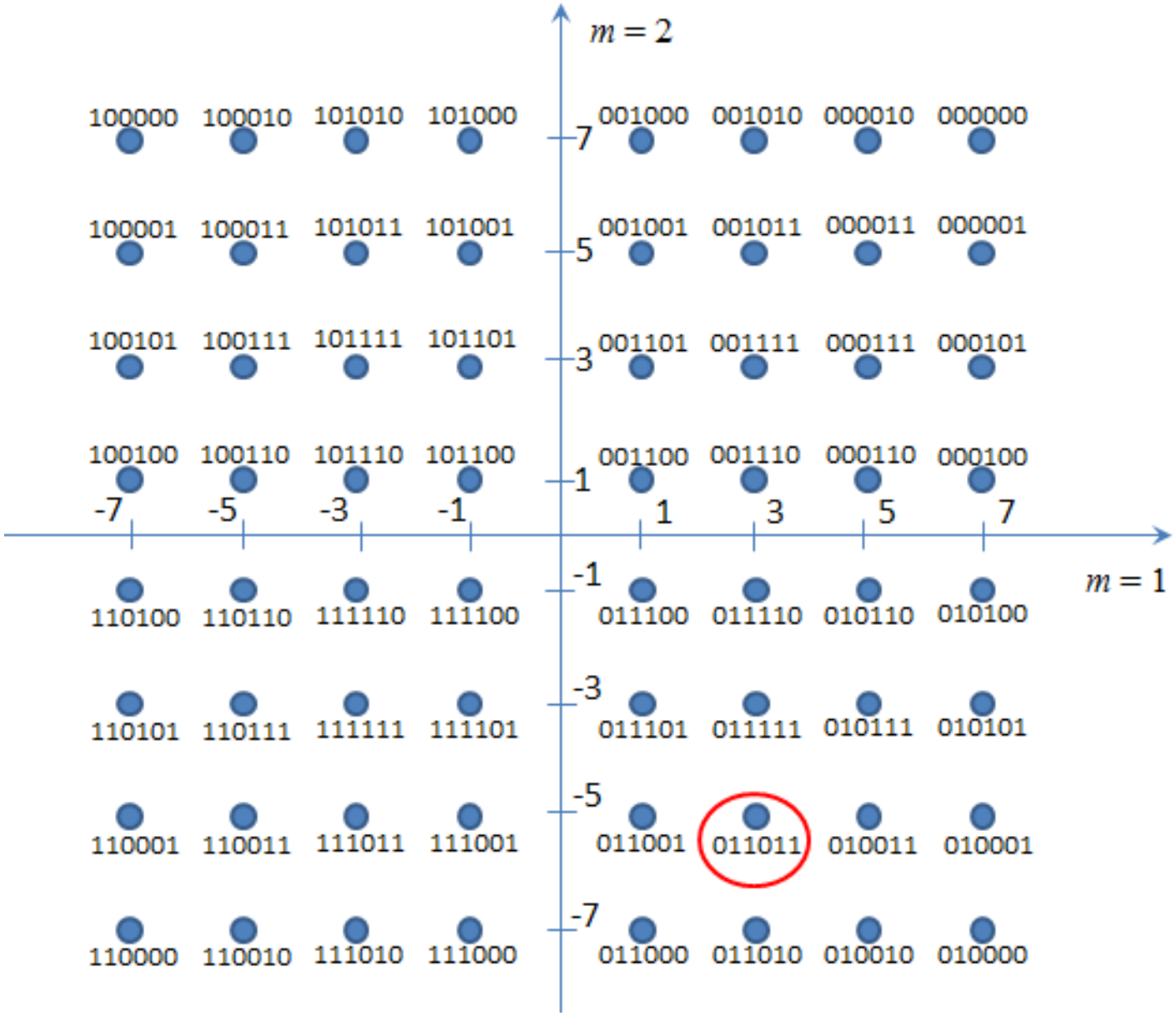
we do:



Information representation is also based on **WHICH subcarrier(s)** are used for signal transmission

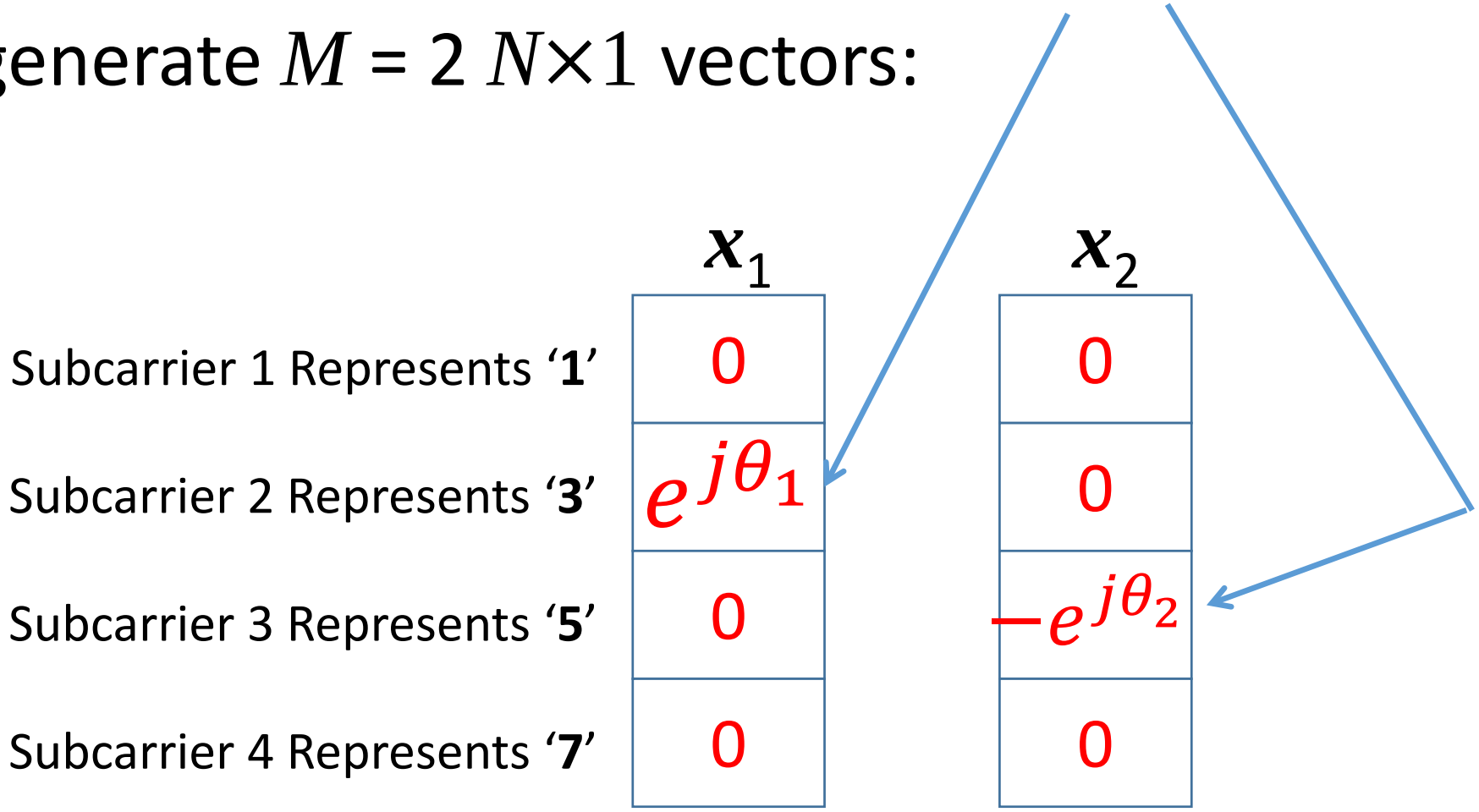
SICE Illustration

- Consider an OFDM system with N = 4 subcarriers
- Information is modeled as a 2-D coordinate system (M = 2). There are a total of 64 coordinate points
- Each coordinate point represents **6-bits** of information
- To transmit ‘011011’ in the red circle we turn on **subcarrier 2** (positive) in one dimension and **subcarrier 3** (negative) in the other dimension



SICE Illustration (Cont.)

- Note that ‘011011’ corresponds to **(3,-5)**
- We generate M = 2 $N\times1$ vectors:



Comparing SICE Against Conventional OFDM

- We generate the OFDM signal vector (in frequency domain) by adding up these two vectors:

x_1		x_2		S_f
0	+	0	=	0
$e^{j\theta_1}$		0		$e^{j\theta_1}$
0		$-e^{j\theta_2}$		$-e^{j\theta_2}$
0		0		0

As Opposed To:

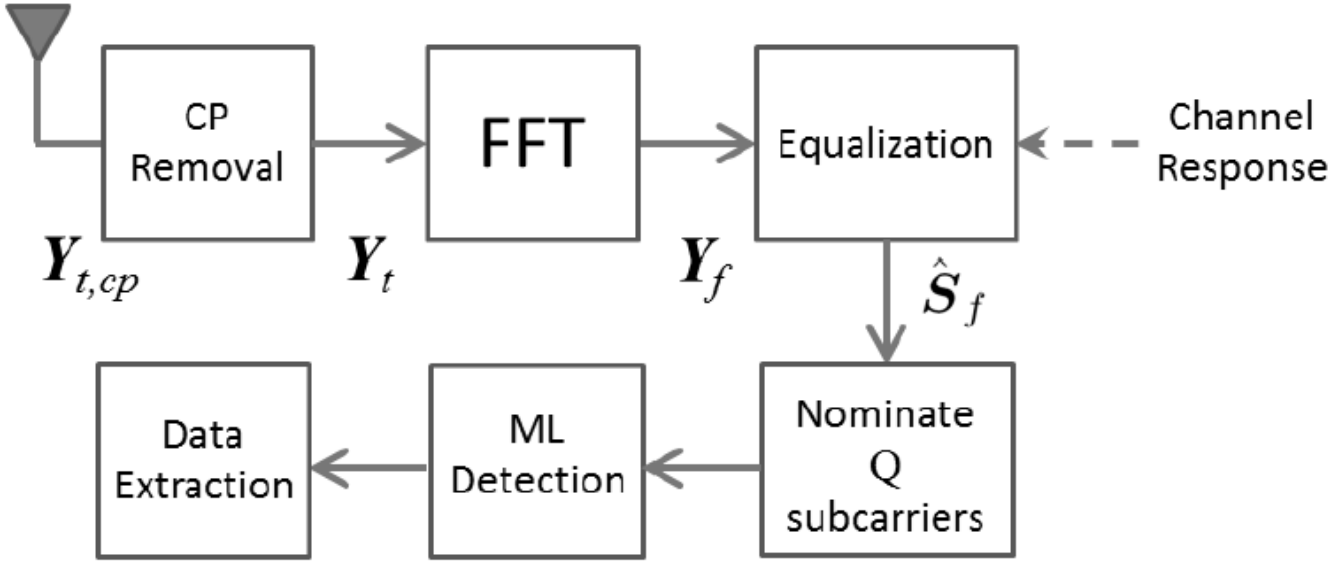
Conventional OFDM
QPSK
QPSK
QPSK
0

- With SICE, only **2 subcarriers** are activated, while the remaining subcarriers are switched off to save power. In contrast, in conventional OFDM, to match the data rate of 6 bits, **3 subcarriers** have to be used to transmit QPSK symbols

Receiver Algorithm on Access Point or Base station

In order to decode the information transmitted by SICE, the receiver will determine:

- The subset of subcarriers that are activated at the transmitter
- The transmitted waveforms on these activated subcarriers



Two-stage receiver processing:

1. Subcarriers identification based on received power
2. ML-detection: exhaustive search over identified subcarriers

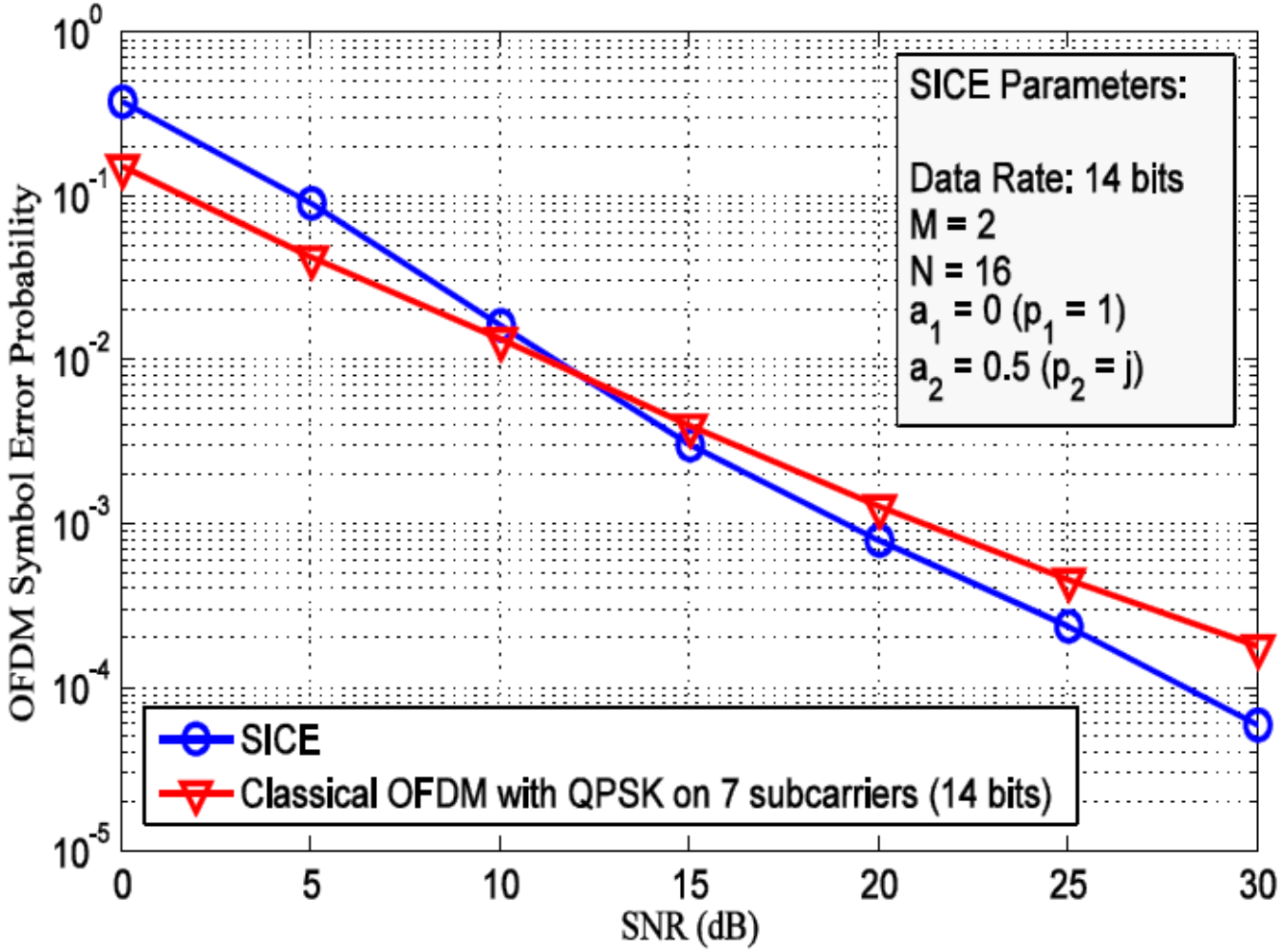
Simulations and Analysis

- General parameters setting and assumptions:
  - Number of subcarriers: N = 64
  - Cyclic prefix (CP) length: 25% of the IFFT output
  - Frequency-selective Rayleigh fading channel with 6 taps
  - Power allocation per activated subcarrier is $1/N$
  - Target data rate: **14 bits** per OFDM symbol
- We evaluate performance in terms of (1) **power efficiency**, (2) **error probability** and (3) **PAPR** for the following two schemes that transmit 14 bits per OFDM symbol:
  - Conventional OFDM: QPSK on 7 subcarriers
  - SICE: $M = 2$, $\theta_1 = 0$, $\theta_2 = 0.5\pi$ on 2 or fewer subcarriers

(1) Power Efficiency of SICE

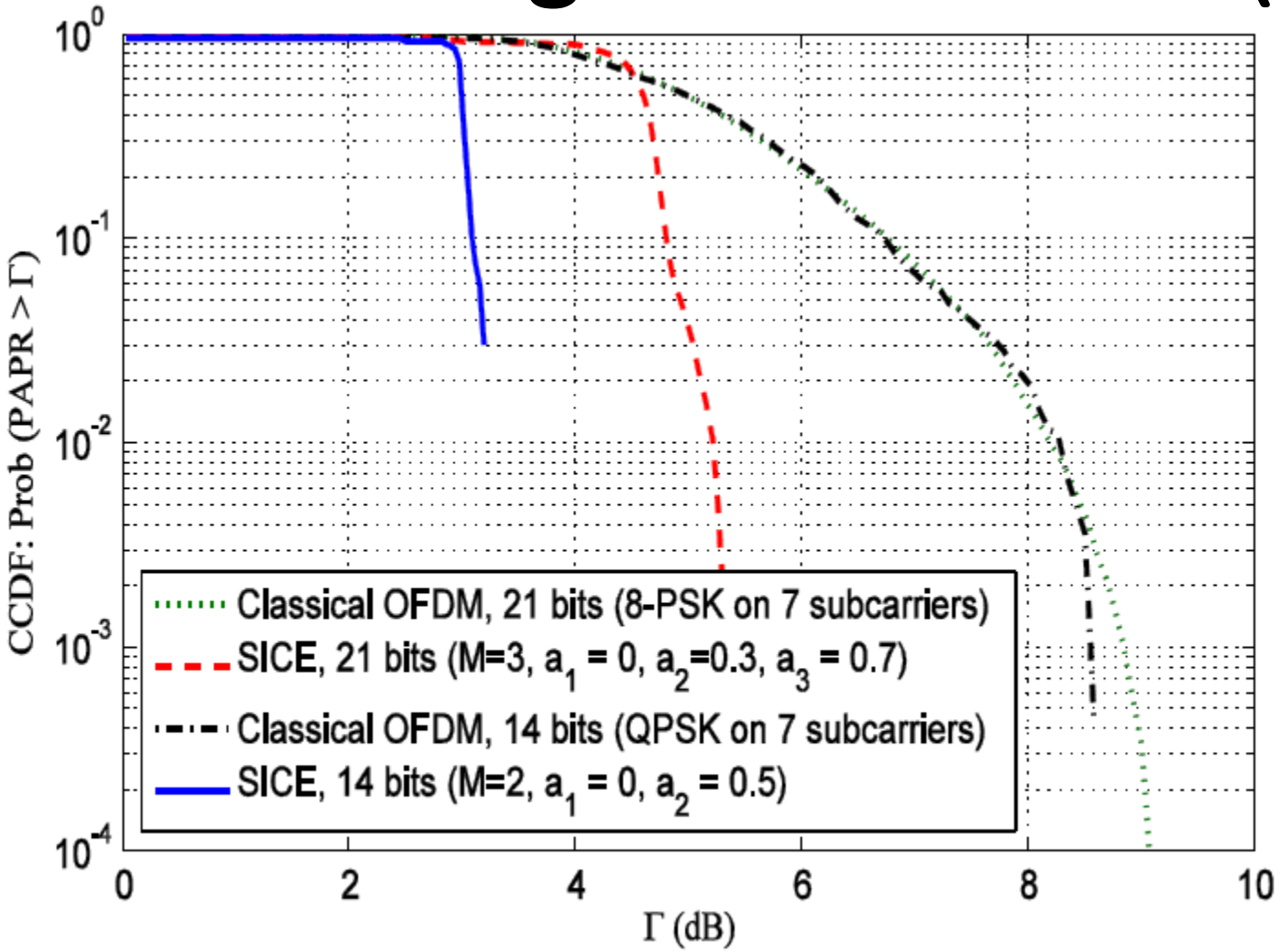
- With the given settings, for a target data rate of 14 bits per OFDM symbol, SICE activates at most $M = 2$ subcarriers
- In contrast, the conventional OFDM using QPSK modulation requires to activate 7 subcarriers in total
- This mean that SICE improves power efficiency by at least 71%

(2) Error Probability



SICE outperforms conventional OFDM when the signal-to-noise ratio (SNR) is sufficiently high

(3) Peak to Average Power Ratio (PAPR)



With SICE, the number of activated subcarriers is significantly reduced. As a result, SICE generally has a much smaller PAPR than conventional OFDM

Conclusion

- For IoT Communication, SICE can be an attractive way of using OFDM:
  - Directly improves power efficiency by using a reduced number of activated subcarriers, and thereby lengthens battery life of IoT devices
  - Maintains similar, or even better, data transmission reliability
  - Delivers low PAPR of the time-domain waveform, so the OFDM signal can be launched in the linear region of the power amplifier without using expensive RF components in IoT devices
- SICE is designed to operate within the OFDM framework. Given that OFDM is the physical-layer for Wi-Fi and 4G, with SICE they have an enormous potential to play key roles in offering power-efficient wireless connectivity for IoT