Enhanced Narrowband IoT (eNB-IoT) Design and Implementation

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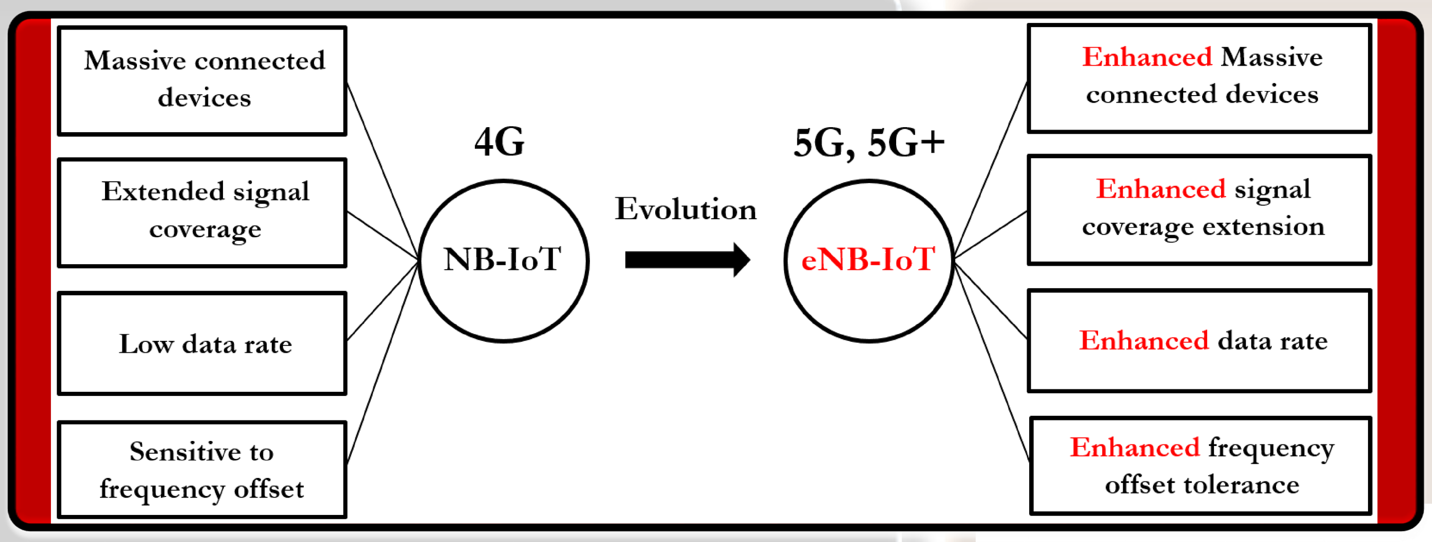
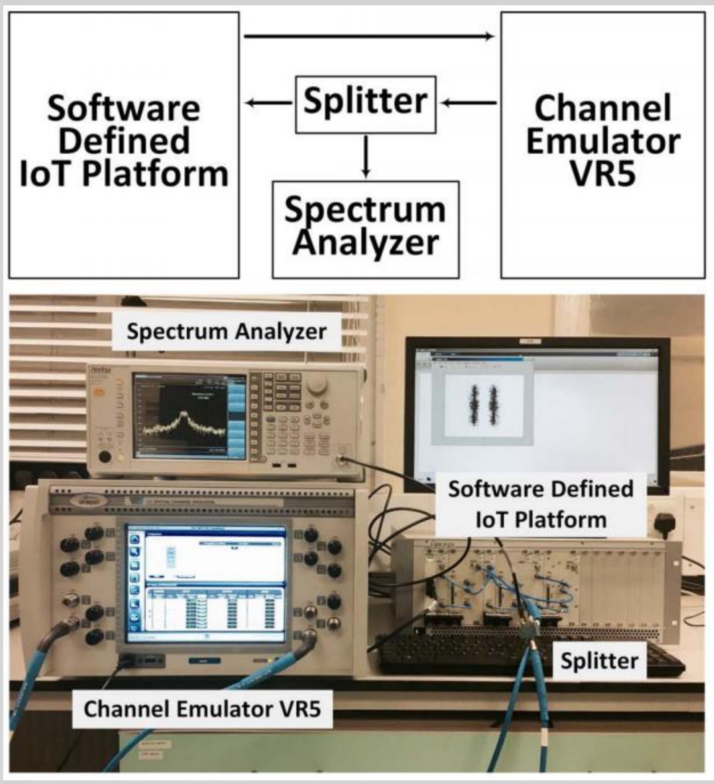
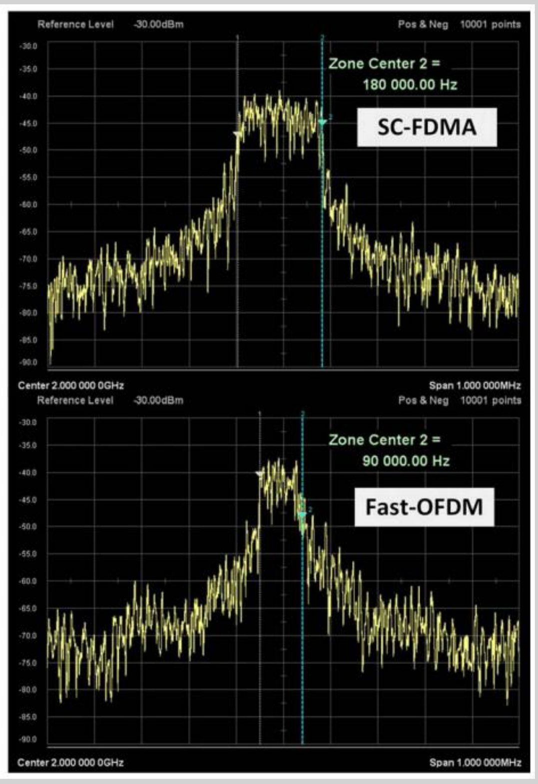
Double Connected Devices

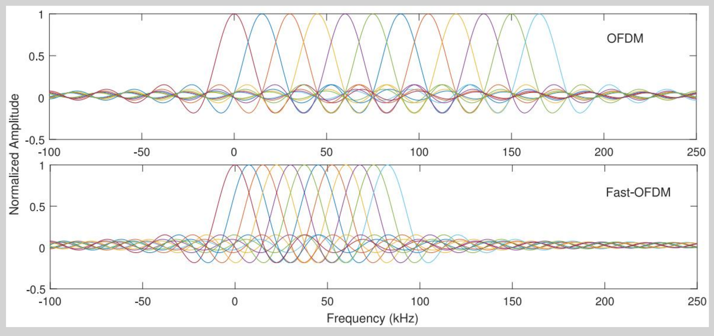
Limitations of existing NB-IoT:
- Each device occupies signal bandwidth of <u>180 kHz</u>.
- More devices require more spectral resources.

Benefits of eNB-IoT:
- Each device occupies half bandwidth, which is <u>90 kHz</u>.
- Bit error rate performance is maintained the same.
- System complexity is maintained the same.

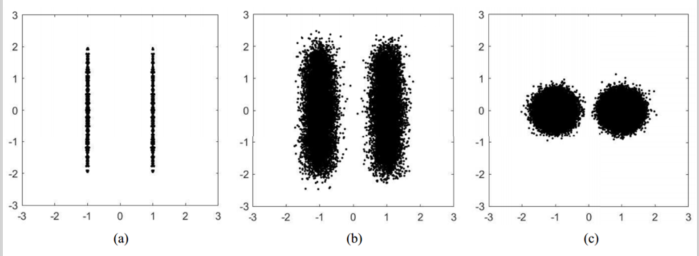








BPSK constellation comparison



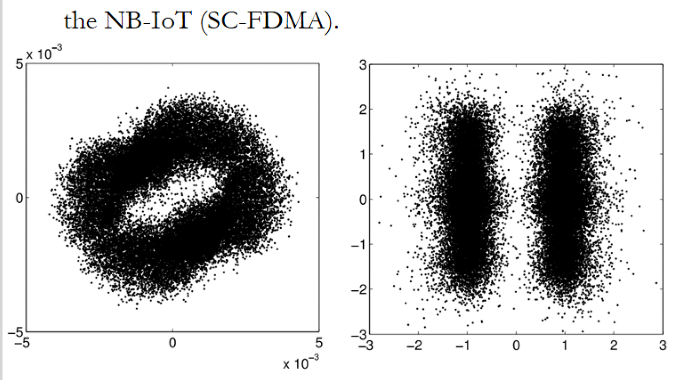
(a) Ideal Fast-OFDM.
(b) Fast-OFDM in AWGN channel at Eb/No = 10 dB.
(c) OFDM in AWGN channel at Eb/No = 10 dB.

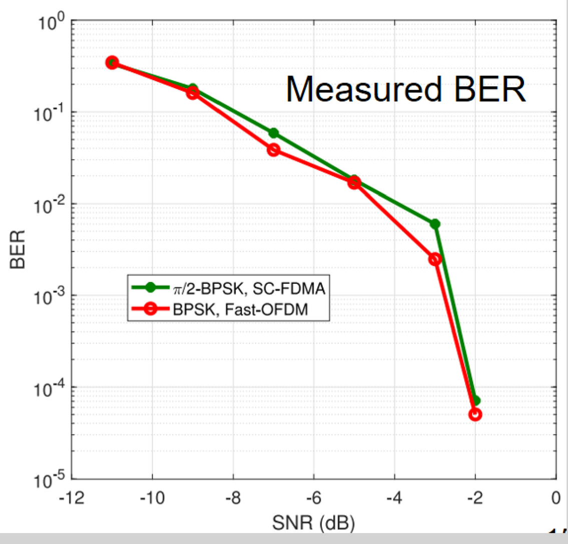
Experimental transmission and reception power and channel conditions

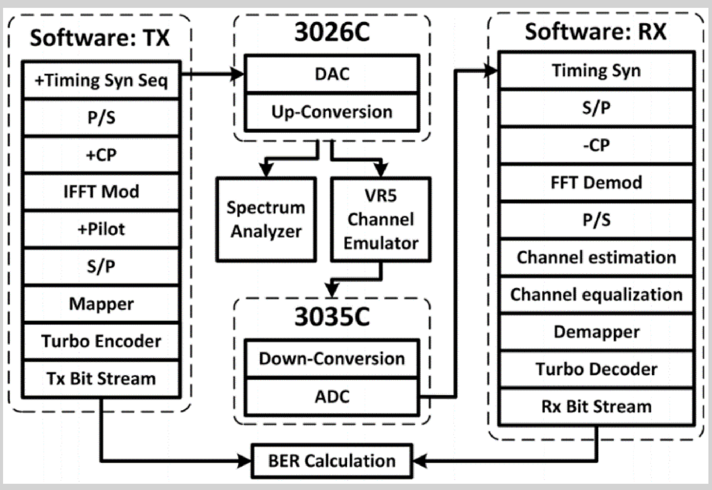
Tx Power(dBm)	Rx Power(dBm)	Path Loss(dB)	Noise Power(dBm)	SNR(dB)
-16	-81	65	-70	-11
-16	-79	63	-70	-9
-16	-77	61	-70	-7
-16	-75	59	-70	-5
-16	-73	57	-70	-3
-16	-72	56	-70	-2

Parameters	SC-FDMA	Fast-OFDM
Occupied Channel Bandwidth (kHz)	180	90
Bit rate (kbit/s)	180	180
Bit rate per sub-carrier (kbit/s)	15	15
Sub-carrier bandwidth (kHz)	15	15
Sub-carrier spacing (kHz)	15	7.5
Sampling rate (MHz)	1.92	1.92
FFT size	128	128
Number of cyclic prefix samples	10	10
Number of guard band sub-carriers	58	58
Number of data sub-carriers	12	12
Modulation scheme	$\pi/2$-BPSK	BPSK

- BPSK constellations for Fast-OFDM before and after equalization.
- eNB-IoT (Fast-OFDM) achieves the same BER as the NB-IoT (SC-FDMA).



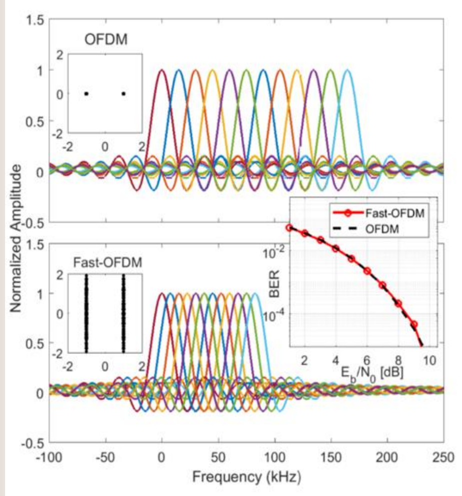


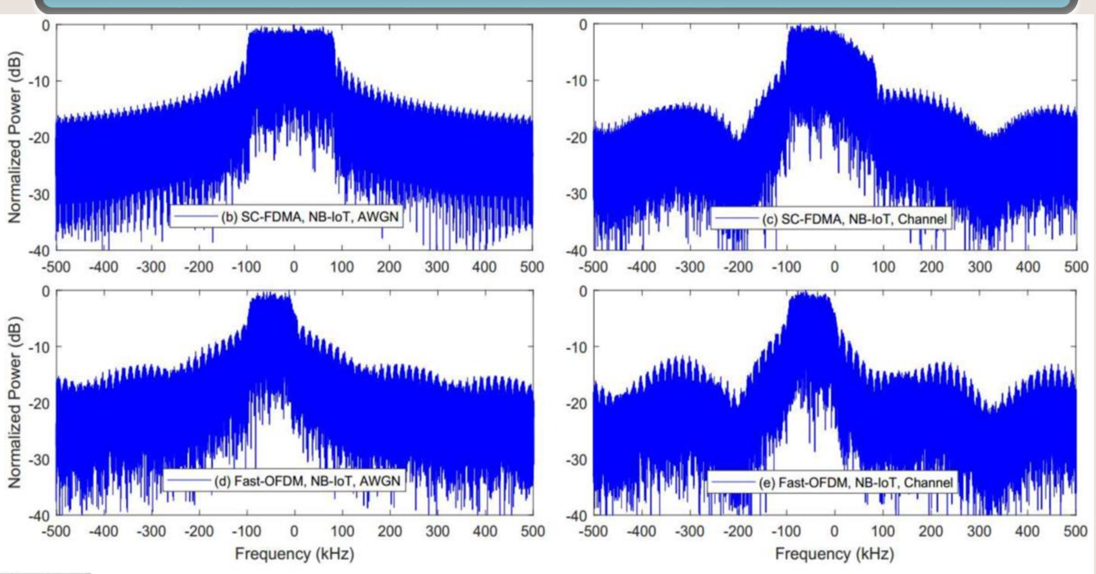


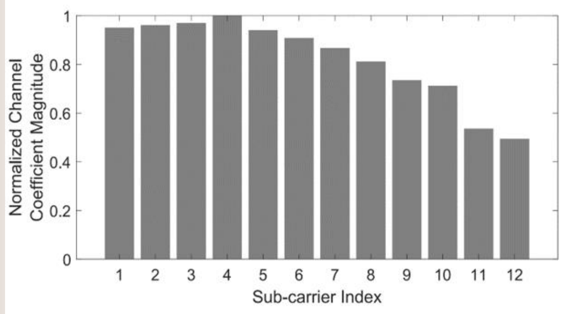
Further Extension of Signal Coverage

Limitations of existing NB-IoT:
- Repetitive transmission results in extra power consumption and time delay.
- Frequency hopping results in Frequency offset.
- Coherence time is violated due to each hop.

Benefits of eNB-IoT:
- Locate the optimal frequency portion associated with high SNR (energy efficient resource allocation).





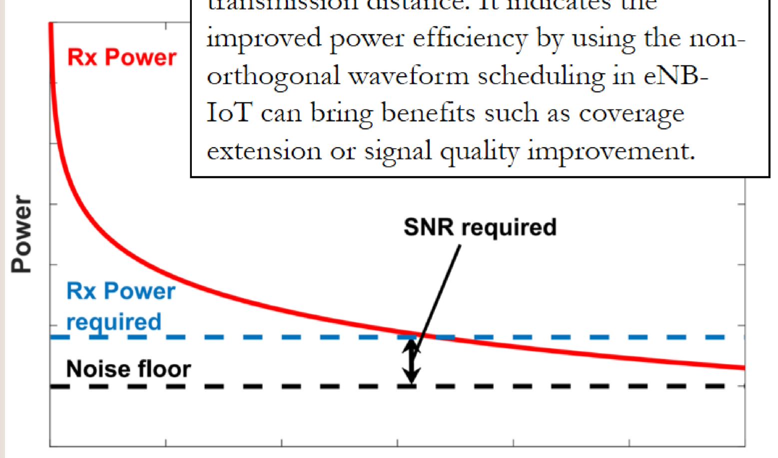


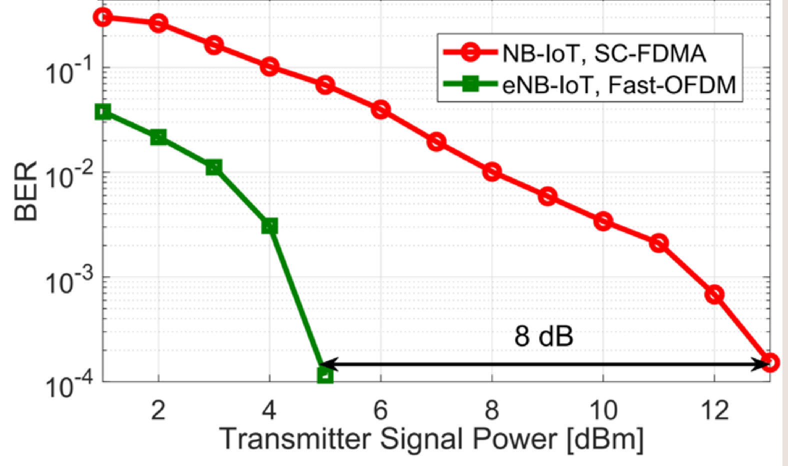
- eNB-IoT can shift the location of the occupied spectrum based on the feedback SNR. A predefined frequency selective channel is tested.
- CSI at each sub-carrier is estimated to indicate SNR

Parameters	SC-FDMA	Fast-OFDM
Center frequency (GHz)	2.4	2.4
Occupied channel bandwidth (kHz)	180	90
Bit rate (kbit/s)	180	180
Bit rate per sub-carrier (kbit/s)	15	15
Sub-carrier bandwidth (kHz)	15	15
Sub-carrier spacing (kHz)	15	7.5
Sampling frequency (MHz)	1.92	1.92
FFT size	128	128
Number of cyclic prefix samples	10	10
Number of guard band sub-carriers	58	58
Number of data sub-carriers	12	12
Modulation scheme	$\pi/2$-BPSK	BPSK

This simulation figure shows that using our adaptive spectrum selection scheduling technique, in order to achieve the same BER performance, eNB-IoT requires lower transmitter signal power. The saved power can be used to extend signal coverage such as deep indoor communications (e.g. basements) where signals are weak.

Correlation of received signal power and transmission distance. It indicates the improved power efficiency by using the non-orthogonal waveform scheduling in eNB-IoT can bring benefits such as coverage extension or signal quality improvement.

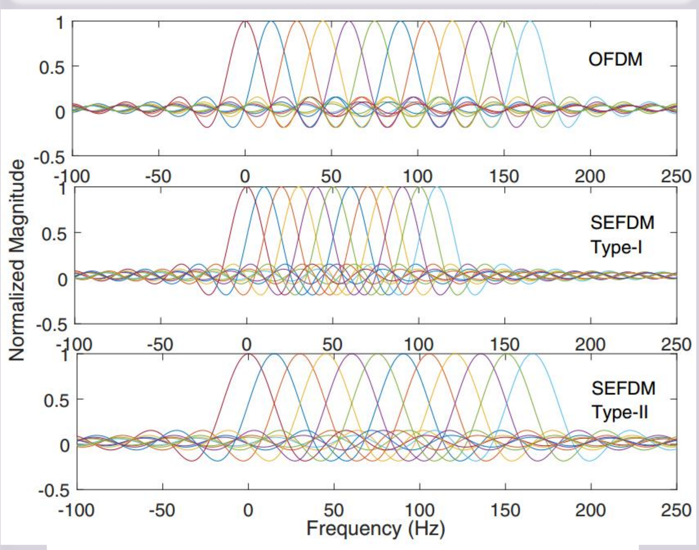




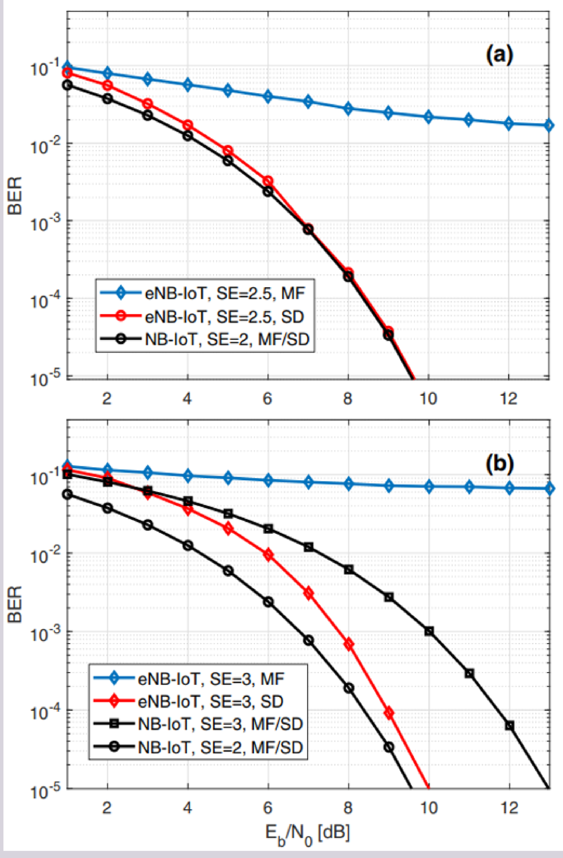
Further Improvement of Data Rate

Limitations of existing NB-IoT:
- Maximum supported modulation format is QPSK.
- For data-driven applications, QPSK is not sufficient.

Benefits of eNB-IoT:
- Data rate can be improved without changing modulation formats.



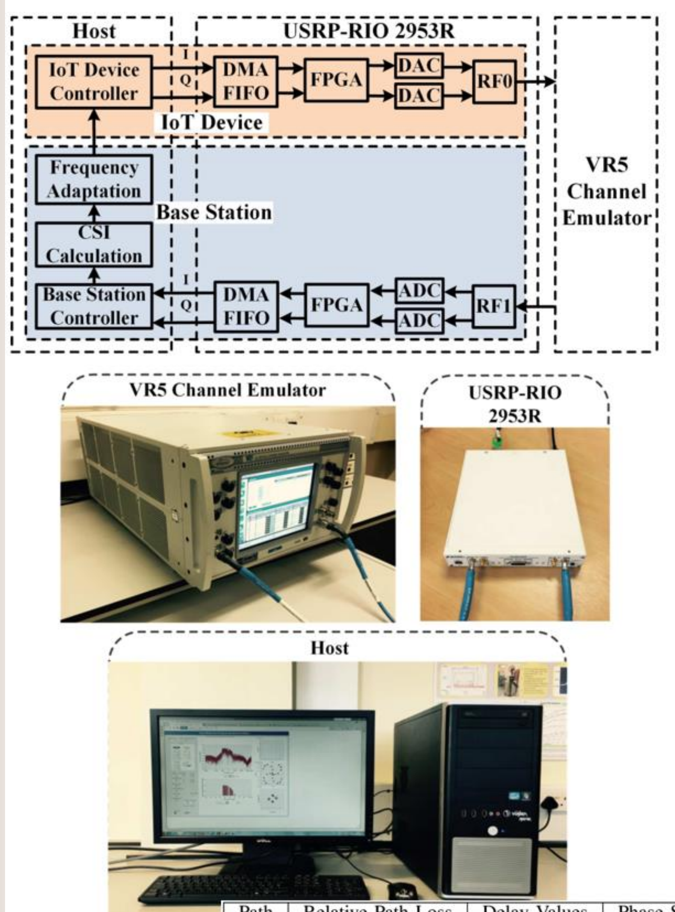
- OFDM (12 sub-carriers, data rate is Rb).
- SEFDM Type-I (12 sub-carriers, α=0.67, data rate is Rb). SEFDM Type-II (12 sub-carriers, α=0.67, data rate is $1.5Rb$).



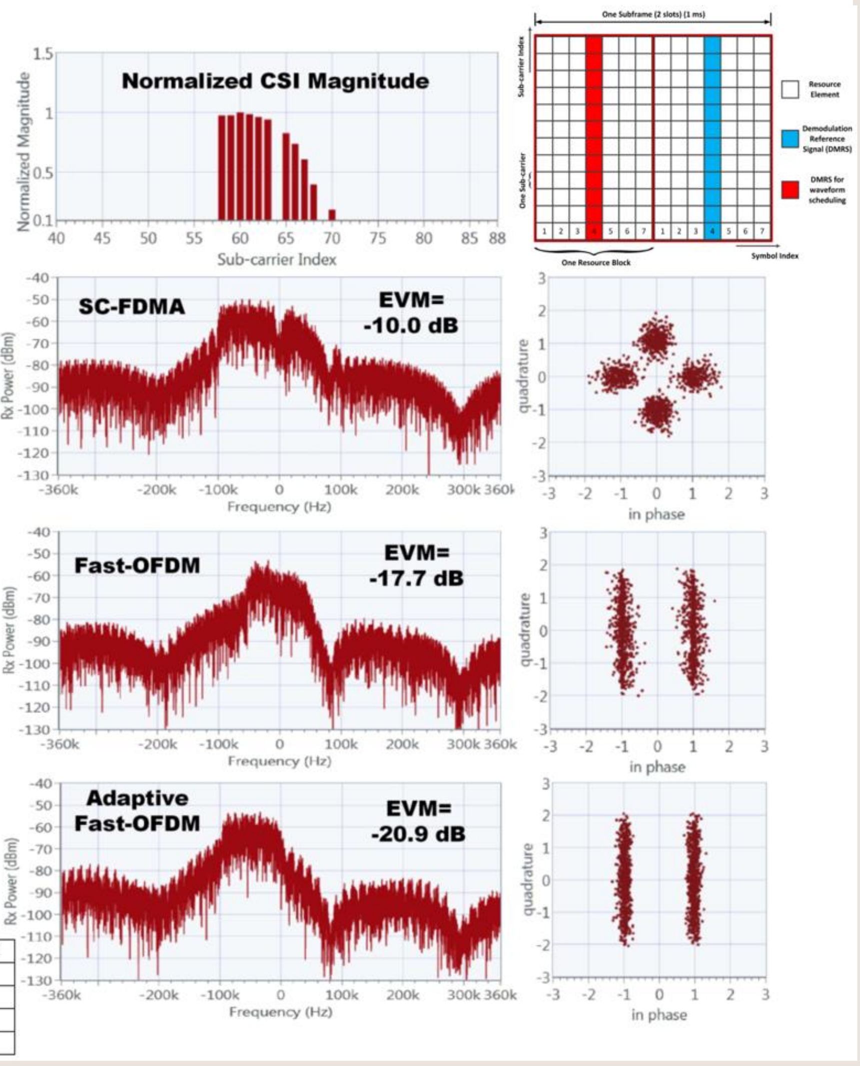
Parameters	SE (bit/s/Hz)	Data rate
NB-IoT	2 (QPSK)	R_b
eNB-IoT	2.5 (QPSK)	$1.25R_b$ (+25%)
NB-IoT	3 (8PSK)	$1.5R_b$ (+50%)
eNB-IoT	3 (QPSK)	$1.5R_b$ (+50%)

Performance of QPSK modulated eNB-IoT signals (a) α=0.8. (b) α=0.67 and QPSK, 8PSK modulated NB-IoT signals.

Non-orthogonal signal waveform is better than dense modulation formats to improve IoT data rate !



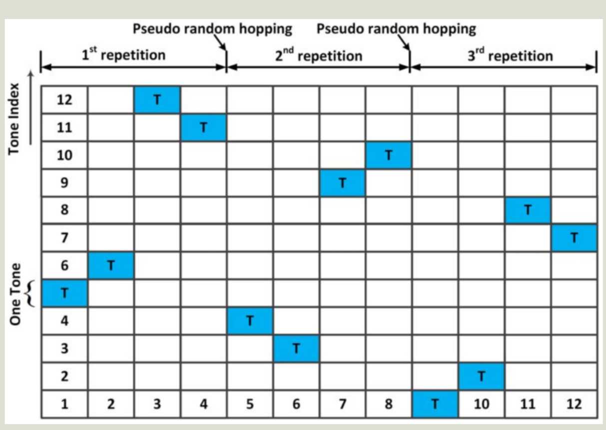
Path	Relative Path Loss	Delay Values	Phase Shift
1	0 dB	0 ns	0
2	5.9 dB	0.52 ns	π
3	8.2 dB	2.08 ns	0
4	3.4 dB	3.64 ns	$3\pi/2$



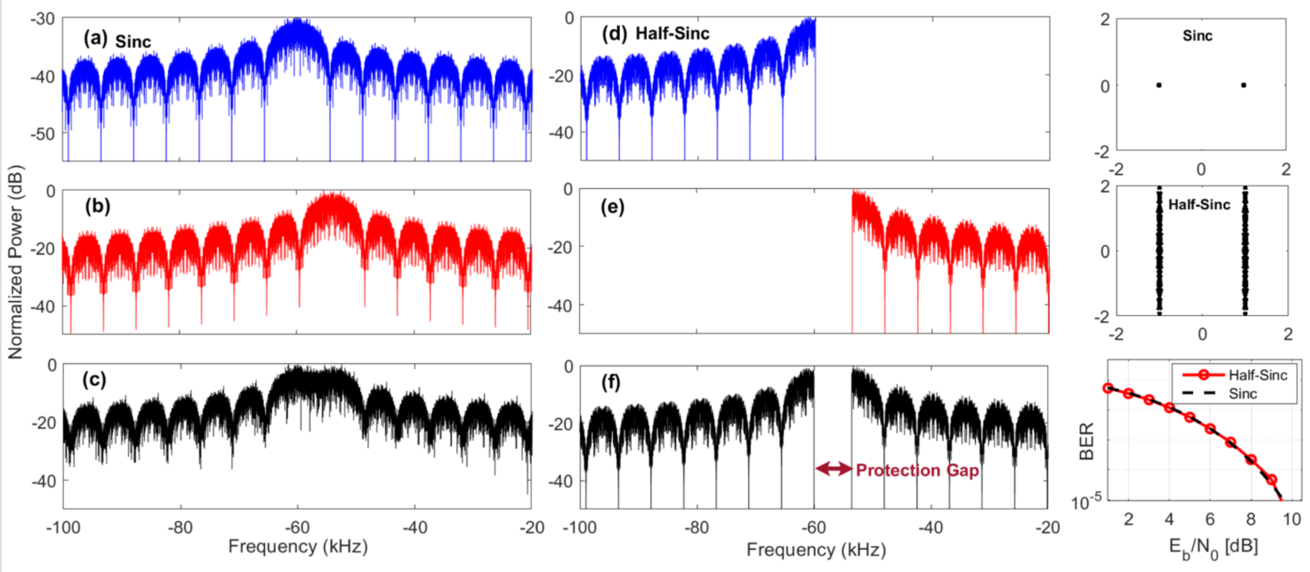
Half-Sinc Single-Tone Waveform

Limitations of existing NB-IoT:
- Retuning of RF front-end introduces frequency offset.
- Out-of-band interference due to the high sinc pulse side lobe.

Benefits of eNB-IoT:
- Half-Sinc Hilbert transform cut out-of-band power leakage while maintain similar complexity.

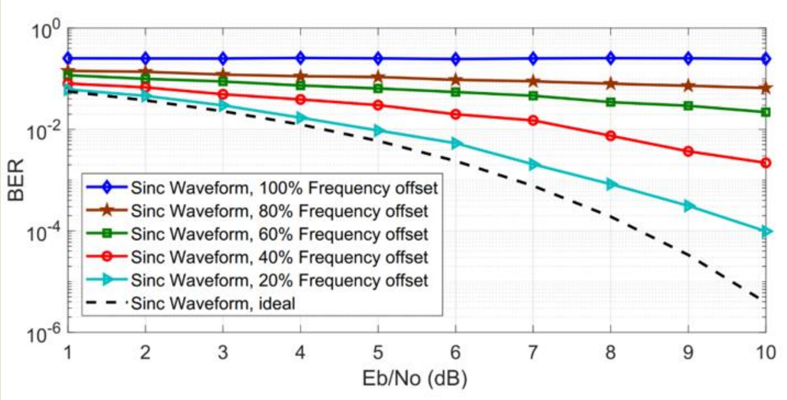


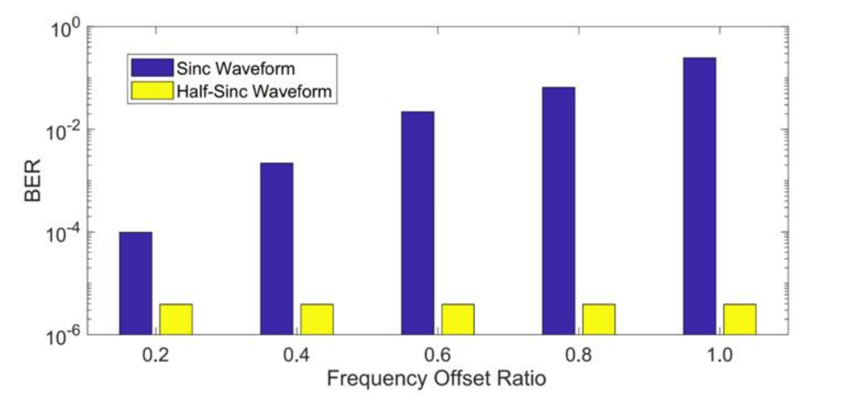
- Hilbert transform is straightford and complexity is reasonable.
- No extra time-domain samples are introduced.

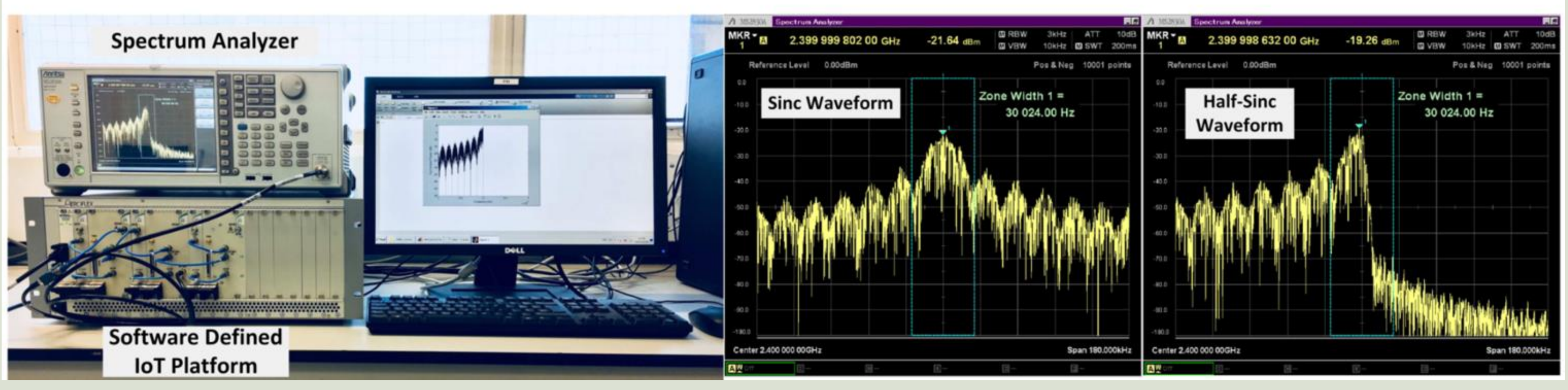


Robust to frequency offset due to the protection gap

- Frequency offset tolerance test up to 100%







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