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Transmission Experiment of Bandwidth Compressed Signals in Realistic Channels

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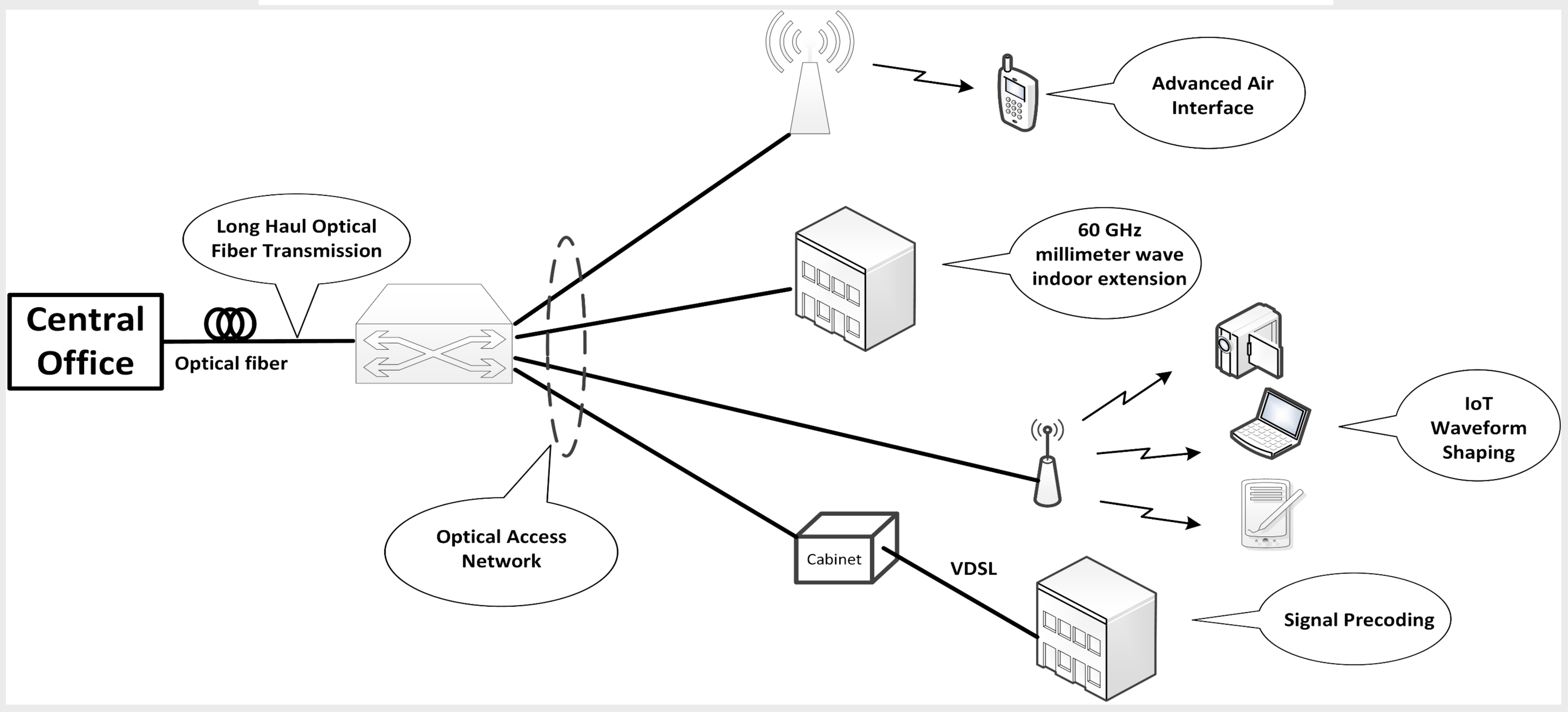
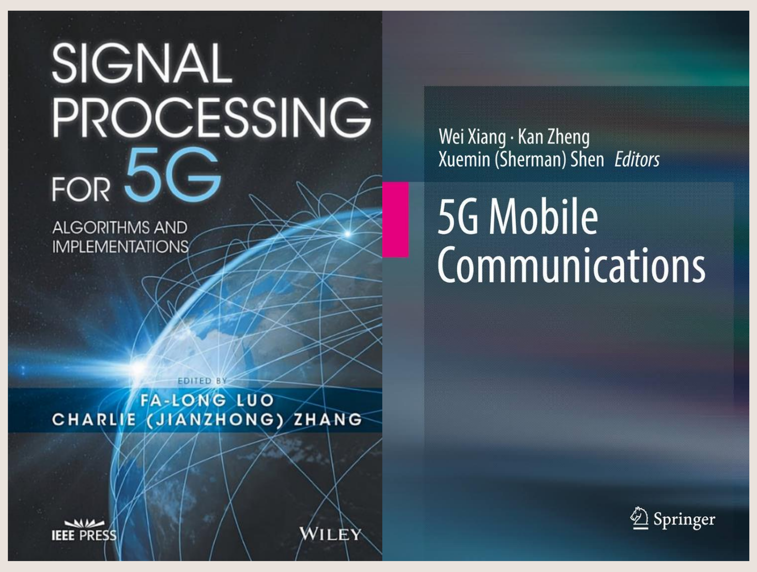
UCL

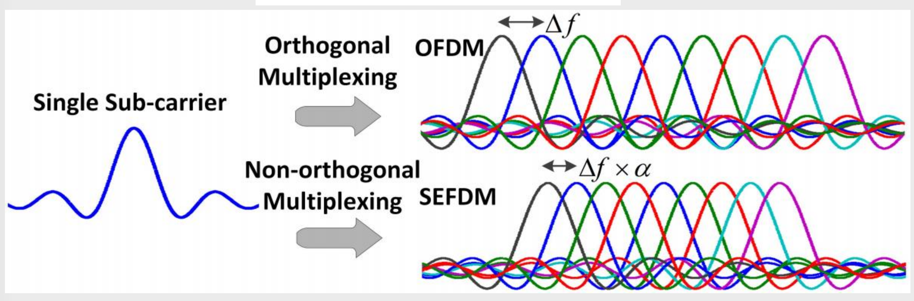
Proposed Topologies for Future SEFDM Beyond 5G Networks

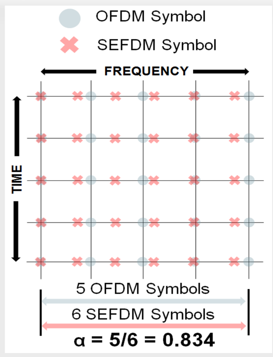


Spectrally efficient frequency division multiplexing (SEFDM) is a multicarrier communication technique developed at UCL in 2003. SEFDM systems demonstrations show the advantages of SEFDM in its potential data rates improvement, power efficiency and transmission distance extension compared to conventional orthogonal communication techniques. Over the past 15 years, the studies of SEFDM have led to more than 100 papers in cross-disciplinary areas at leading international journals and conferences. In 2016, SEFDM was regarded as one of the potential 5G techniques and was included in two renowned 5G books, namely: ***Signal Processing for 5G: Algorithms and Implementations (Wiley, 2016) and Key Enabling Technologies for 5G Mobile Communications (Springer, 2016).***



What is SEFDM





The sub-carriers packing schemes of OFDM and SEFDM are compared. It is evident that the SEFDM waveform packs sub-carriers closer leading to bandwidth saving at the cost of self-created inter carrier interference (ICI).

Indoor 60 GHz mmWave Signal Transmission

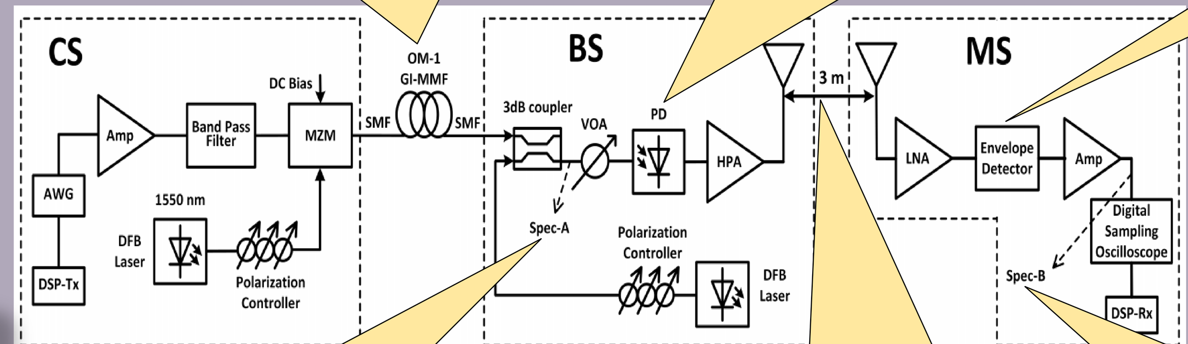
Gross bit rates:
OFDM: 2.25Gbit/s
SEFDM: 3.75Gbit/s

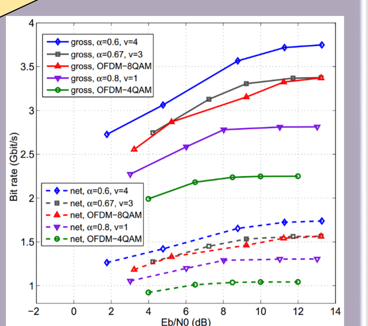
Parameters	Values
Millimeter wave frequency	60 GHz
Intermediate frequency	1.8 GHz
Baseband signal sampling frequency	3 GHz
Bandwidth of baseband signal	1.125 GHz
AWG sampling frequency	12 GHz
Oscilloscope sampling frequency	50 GHz
Length of MMF fiber	250 meters
Distance of mm-wave wireless link	3 meters
Modulation scheme	4QAM
IFFT/FFT size	128
Data sub-carriers	48; 60; 72; 80
Sub-carrier baseband bandwidth	23.4 MHz
Sub-carrier spacing	$\alpha \times$23.4 MHz
Cyclic prefix	10
Channel coding	(7,5) RSC code
Coding rate	R_{code}=1/2

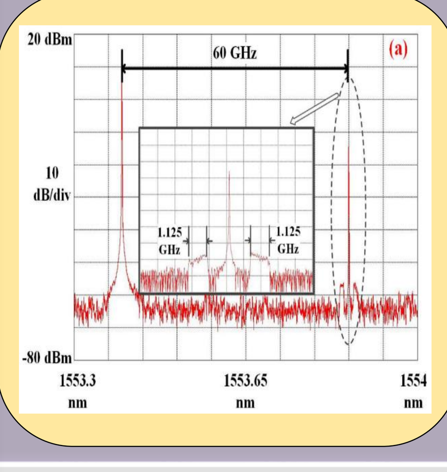
250 metres fibre length (multimode) fed by and feeds single mode fibres.

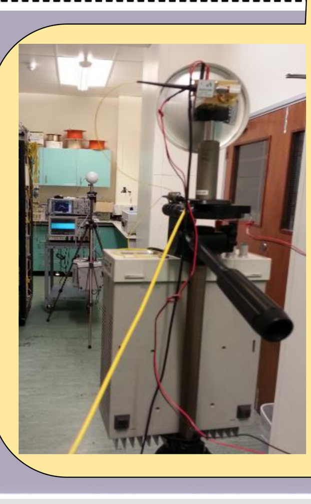
60 GHz mm-wave signal generated at the photodiode, from two optical signals. Method based on an uncorrelated remote heterodyne detection (RHD) concept. This optical scheme is low-cost and can be easily modified by adjusting the two lasers wavelength separation to give different mm-wave carrier frequencies.

Envelope detector used to down-convert the 60 GHz millimeter wave signal to basedband. This is a low cost and robust technique, with high resistance to phase noise.

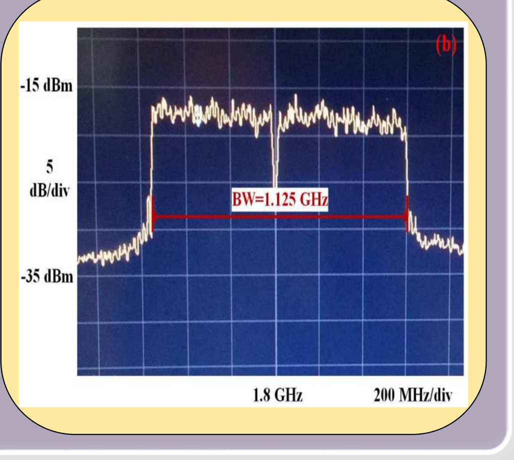








- 60 GHz parabolic antennas have 30 dBi gain; and 3 dB beamwidth of 3.1◦ are employed.
- A 30 dB gain high power amplifier (HPA) at the transmitter and a 30 dB gain low noise amplifier (LNA) at the receiver.
- Transmission distances from few cm to 3 metres.



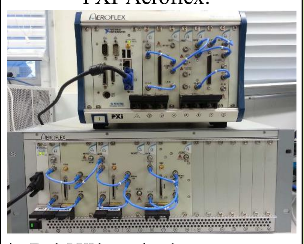
Advanced Air Interface Demonstration

Testbed

Channel emulator-VR5:

Hardware emulation of various wireless channels including standard 3GPP- TR 36.104 LTE channels
- Extended Pedestrian A (EPA)
- Extended Vehicular A (EVA)
- Extended Typical Urban (ETU).

PXI-Aeroflex:

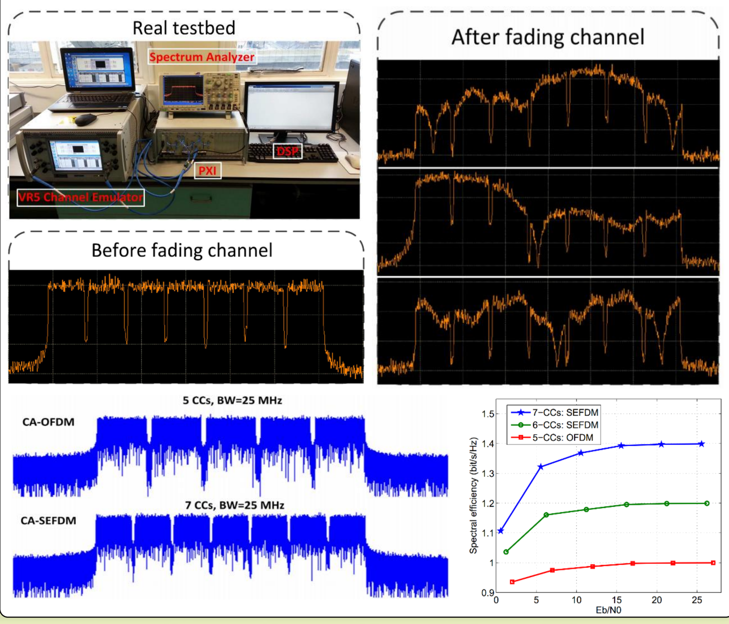


- Each PXI has a signal generator, a clock and a signal digitizer.
- Carrier frequency ranges from 100 kHz to 6 GHz.
- Up to 90 MHz RF modulation bandwidth.
- Up to 512 MHz sampling rate.
- Each 32 bit sample word consists of 14 bit I data, 14 bit Q data and 4 bit marker data.

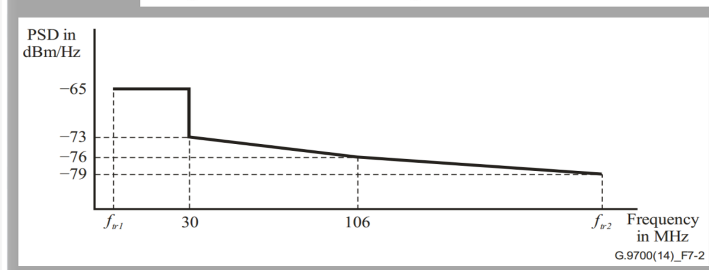
Compressed Carrier Aggregation

- LTE channel model: Extended Pedestrian A (EPA)
- Central carrier frequency: 2 GHz
- Sampling frequency: 61.44 MHz
- Total channel bandwidth: 25 MHz
- Sub-carrier baseband bandwidth: 15 kHz
- Sub-carrier spacing: α×15 kHz
- FFT size: 4096

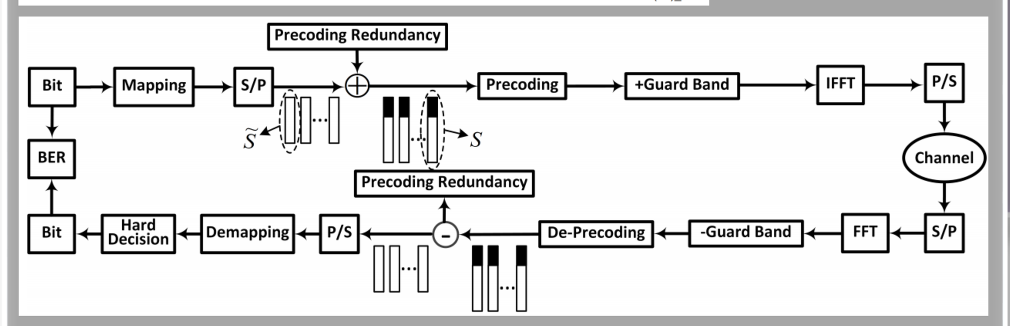
Bit rates:
LTE: 50Mbit/s
SEFDM: 70Mbit/s

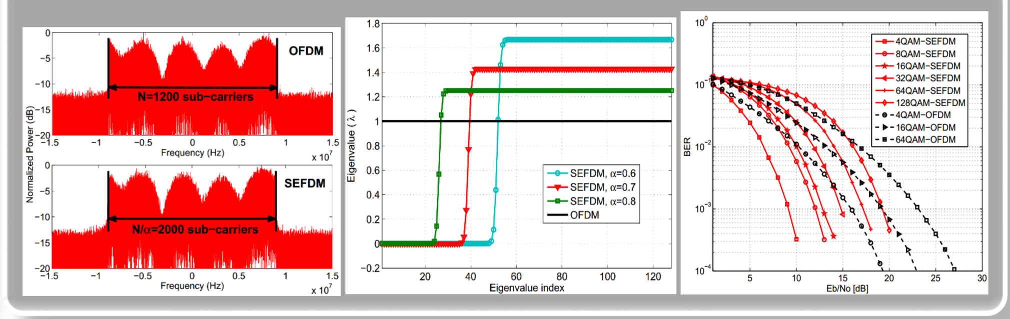


Signal Precoding for DSL Communication

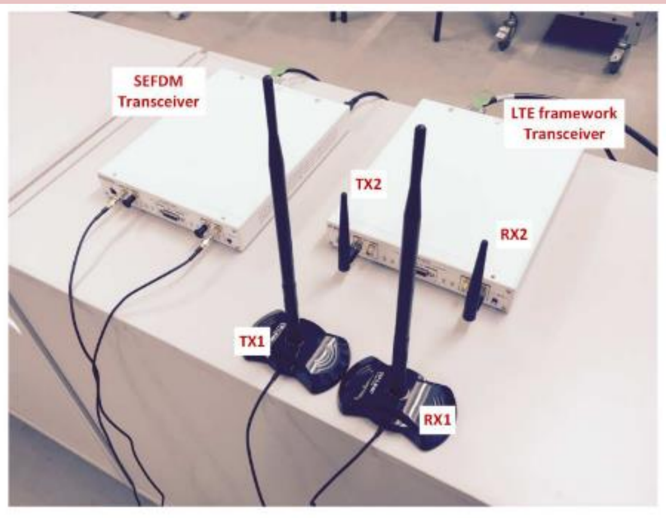


128QAM-SEFDM outperforms 16QAM-OFDM



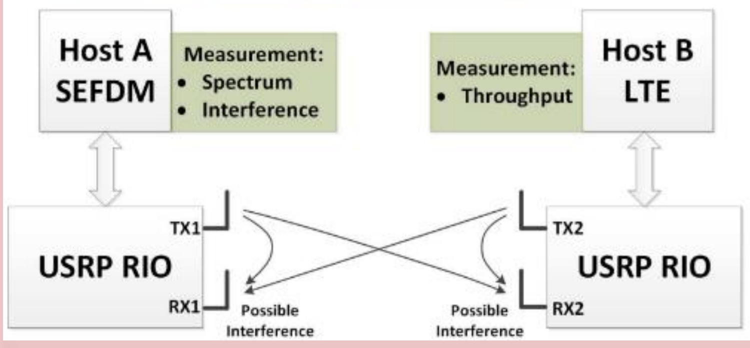


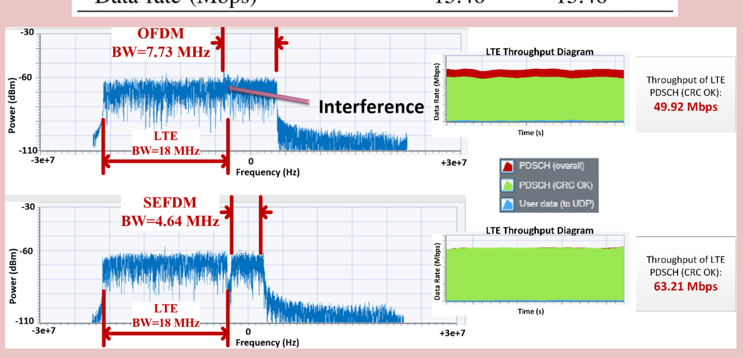
Over-The-Air Testing for 4G and 5G Signals Coexistence Using USRP



➢OFDM: LTE throughput can reach 49.92 Mbps
➢SEFDM: LTE throughput can reach 63.21 Mbps

Parameters	OFDM	SEFDM
Central carrier frequency (GHz)	2.412	2.412
Modulation scheme	4QAM	4QAM
Sampling rate (MHz)	45	45
FFT size	1024	1024
Number of data sub-carriers	176	176
Bandwidth compression factor	1	0.6
Sub-carrier spacing (kHz)	44	26.4
Data bandwidth (MHz)	7.73	4.64
Data rate (Mbps)	15.46	15.46

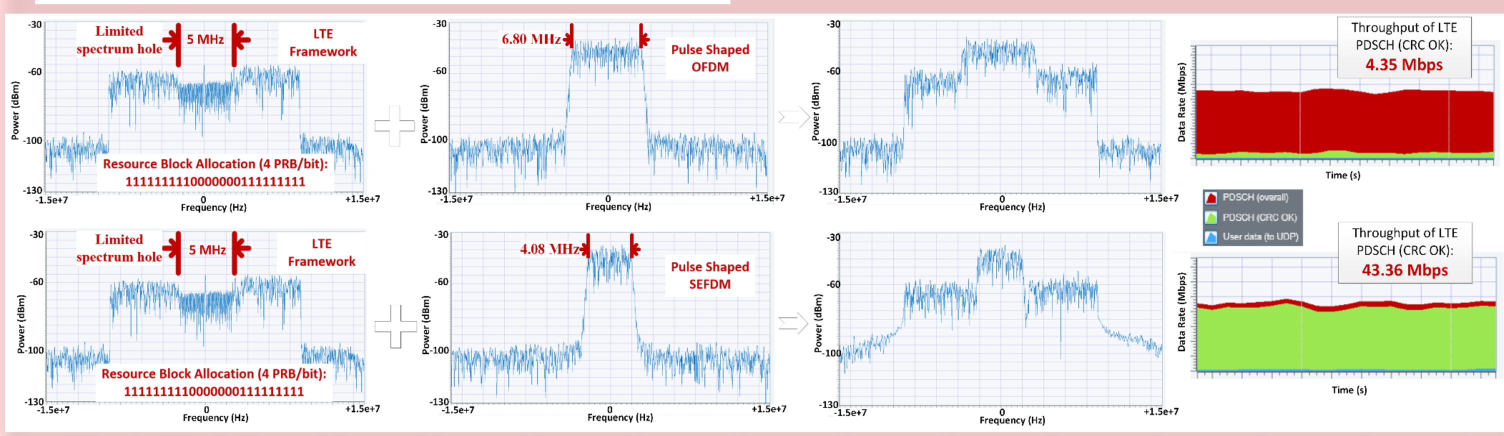




Parameters	OFDM	SEFDM
Central carrier frequency (GHz)	2.4	2.4
Modulation scheme	4QAM	4QAM
Sampling rate (MHz)	30	30
FFT size	128	128
Number of data sub-carriers	29	29
Roll-off factors	1	1
Bandwidth compression factor	1	0.6
Data bandwidth (MHz)	6.80	4.08
Data rate (Mbps)	13.60	13.60

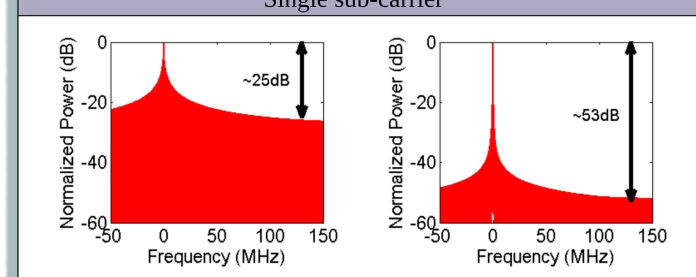
Coexistence of pulse shaped SEFDM/OFDM and LTE signals in a limited spectrum hole at baseband frequency.

➢OFDM: LTE throughput can reach 4.35 Mbps
➢SEFDM: LTE throughput can reach 43.36 Mbps



IoT Waveform Shaping: Coexistence of 4G and 5G

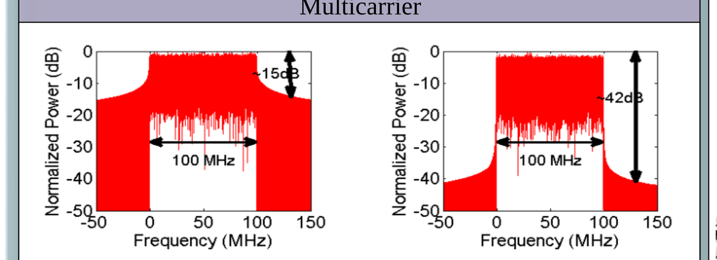
Single sub-carrier



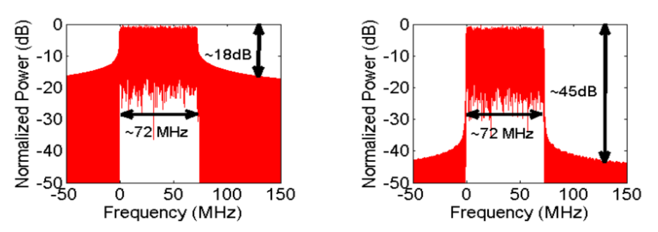
(a) No shaping. (b) RRC shaping.

- The RRC shaped sub-carrier has a much lower out-of-band power leakage.
- It indicates that the interference from an RRC shaped sub-carrier is significantly reduced and it may only affects adjacent sub-carriers.

Multicarrier



(a) Rectangular shaped OFDM. (b) RRC shaped OFDM.



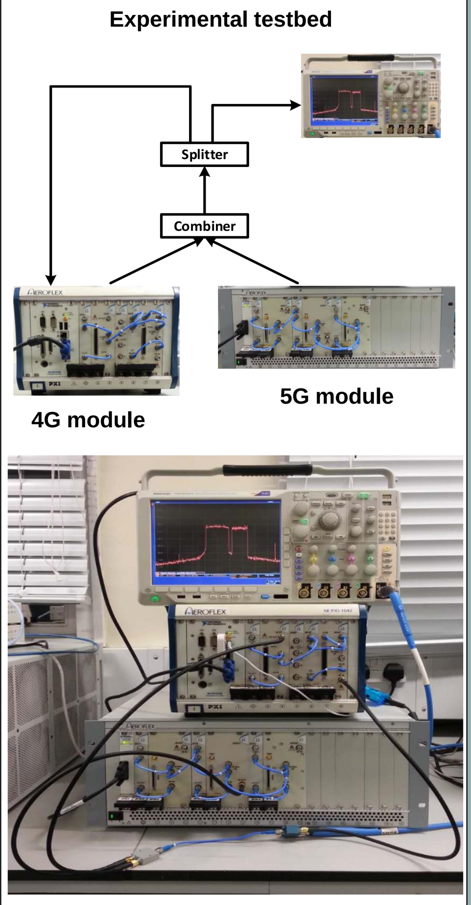
(c) Rectangular shaped SEFDM. (d) RRC shaped SEFDM.

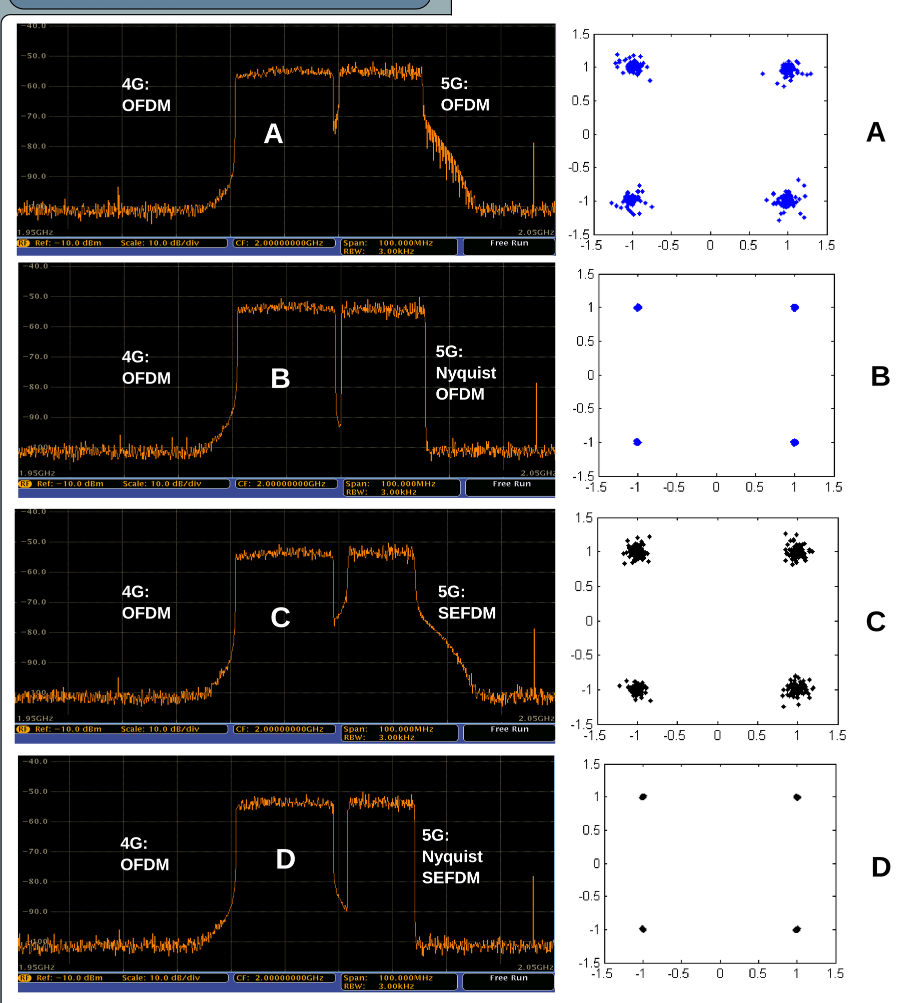
- (a)(b) shows OFDM. Using a root raised cosine (RRC) filter, the out-of-band power leakage is reduced by 27dB.
- (c)(d) shows SEFDM. The bandwidth is compressed by 28%. Using a root raised cosine (RRC) filter, the out-of-band power leakage is reduced by 27dB.

4G Testbed (OFDM)
- Central carrier frequency: 2 GHz
- Sampling frequency: 30.72 MHz
- Total channel bandwidth: 18 MHz
- Sub-carrier baseband bandwidth: 15 kHz
- Sub-carrier spacing: 15 kHz
- FFT size: 2048

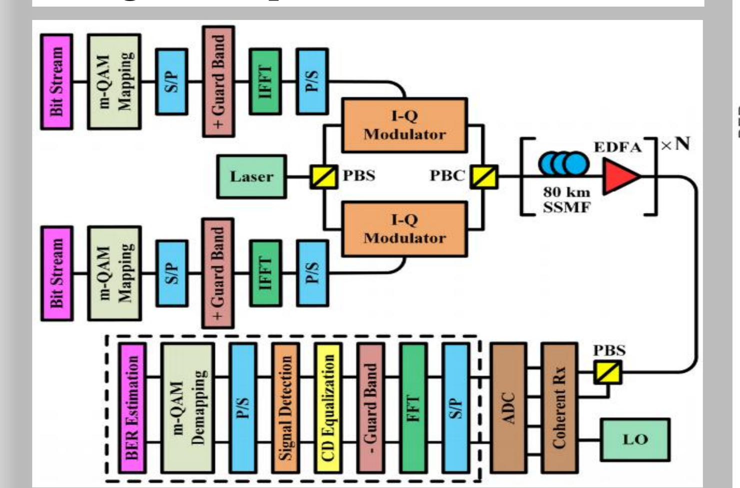
5G Testbed (Nyquist-SEFDM)
- Central carrier frequency: 2 GHz+18 MHz
- Sampling frequency: 30.72 MHz
- Total channel bandwidth: 15 MHz
- Sub-carrier baseband bandwidth: 240 kHz
- Sub-carrier spacing: α × 240 kHz
- Roll-off factor β=0.5
- FFT size: 128

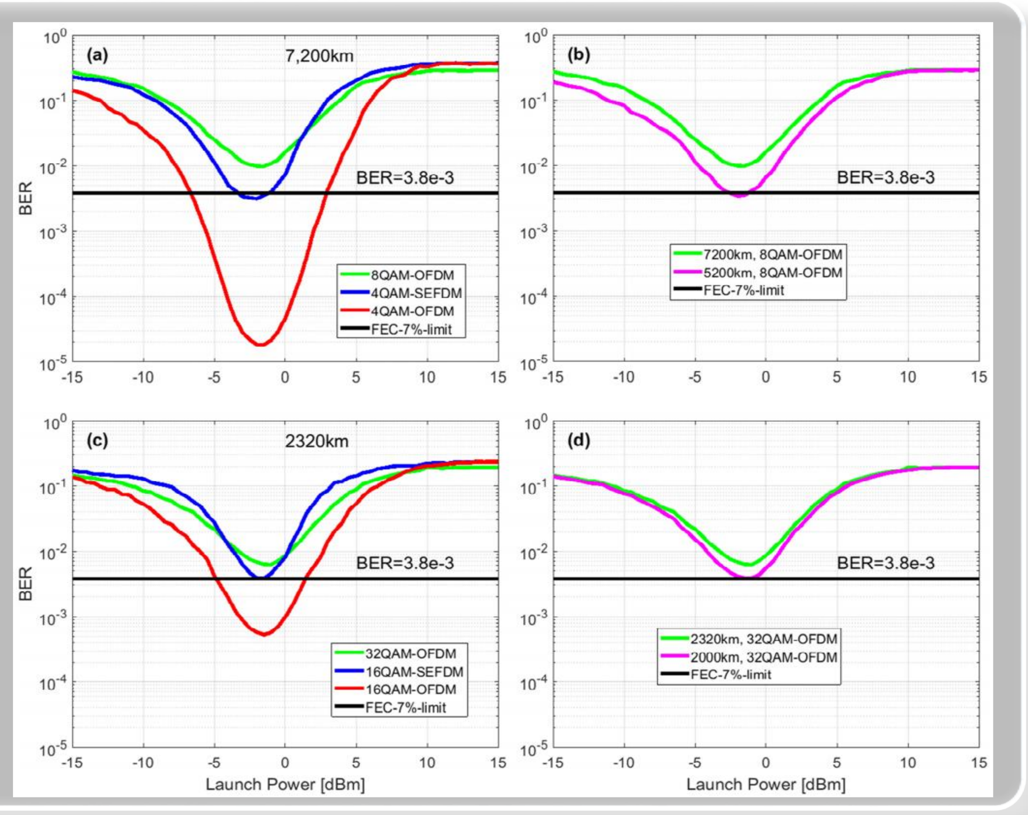
Nyquist-SEFDM:
- **Saves bandwidth**
- **No impact on 4G signals**





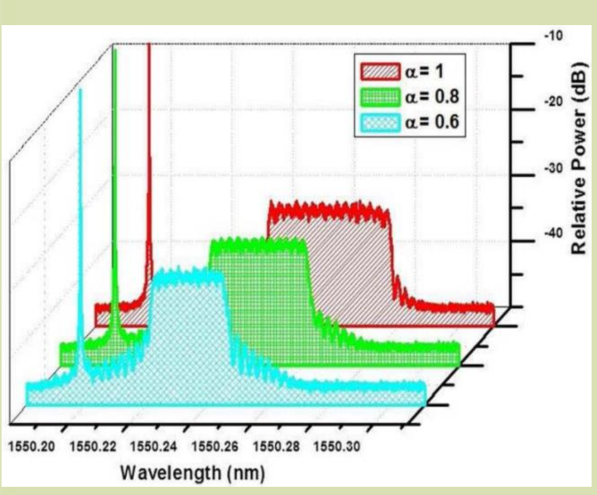
Long Haul Optical Fiber Transmission

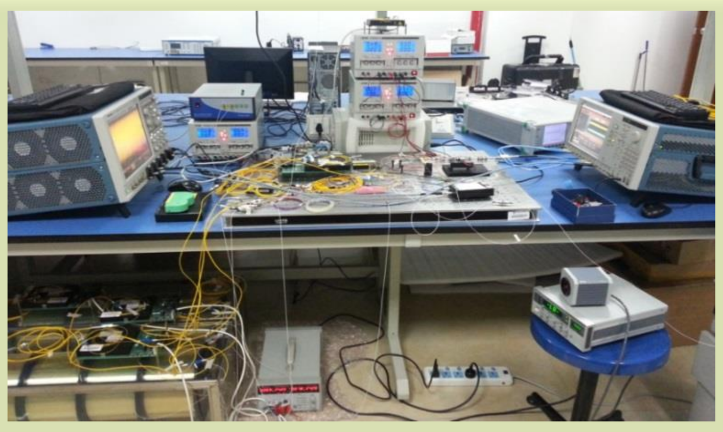


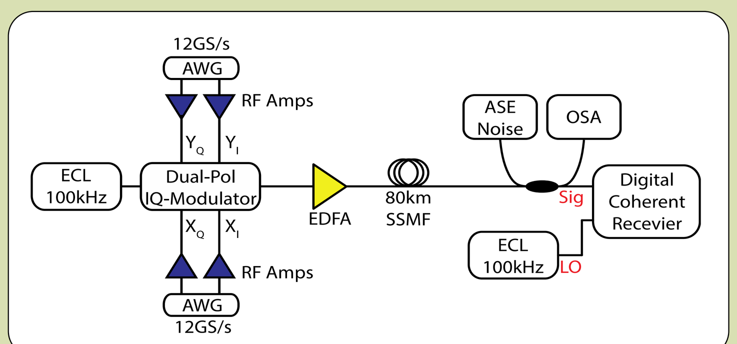


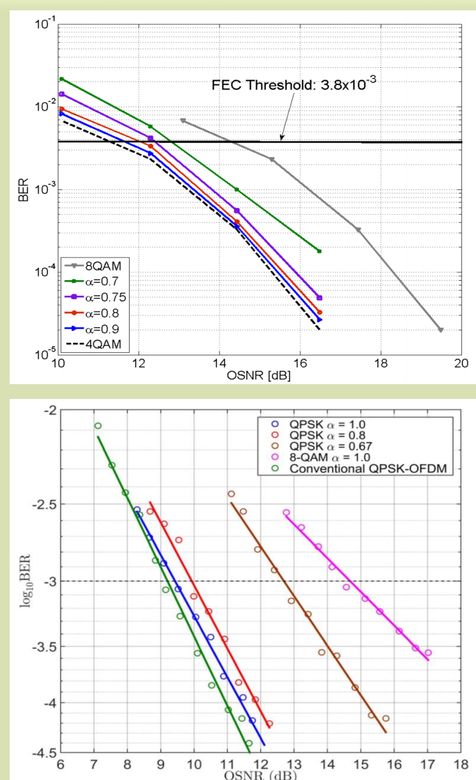
At the same data rate, the 4QAM-SEFDM signal has ~50% reach advantage in enabling transmission over 7200 km while the 8QAM-OFDM signal can only reach 4800 km.

Optical Access Network Testbed









By transmitting the same amount of data, SEFDM can greatly save optical spectral resources.

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