Design and Prototype of Next Generation Internet of Things

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Communications and Information Systems Group UCL Department of Electronic and Electrical Engineering **Downlink Scheme Indoor Experiment** Multi-user MIMO-OFDM Platform **SEFDM Signal Waveform** Users Controller **Precoding Schemes** Precoding architecture of **Base Station** MU-MIMO-OFDM PCIe switch box CPS-8910 Work station Frequency (Hz) 8-channel clock distribution OctoClock CDA-2990 \square OFDM (12 sub-carriers, data rate is Rb). Precoding architecture of ☐ SEFDM Type-I (12 sub-carriers, bandwidth MU-MIMO-SEFDM USRP-RIO USRP-RIO USRP-RIO compression ratio is α =0.67, data rate is Rb). 2953R 2953R The self-created ICI challenges signal detection. Two precoding methods are available ☐ SEFDM Type-II (12 sub-carriers, bandwidth (a) Zero Forcing Precoding (ZFP) compression ratio is α =0.67, data rate is 1.5Rb). (b) Constructive Interference Precoding (CIP) **ZF** Precoding CI Precoding NB-IoT: OFDM outperforms ZF precoding when eNB-IoT: SEFDM Type-II higher interference (a) MU-MIMO-OFDM (b) **MU-MIMO-SEFDM** (higher bandwidth MIMO Precoding=1 MIMO Precoding=1 $r^{(i)} = x_I^{(i)} \mathbf{h}_I + x_2^{(i)} \mathbf{h}_I$ MIMO Precoding=1 compression) Waveform Precoding=0 Waveform Precoding=1 Waveform Precoding=0 → eNB-loT EVM= Simulation ZF-Precoding, BW-Compression=15% OFDM EVM= → BER: eNB-loT CI-Precoding, BW-Compression EVM= 8QAM -35.0 dB ■ BER: NB-IoT 8PSK **QPSK Experimental CI Precoding Performance** CI Precoding Constellation Interfered Constellation EVM= 16QAM *-36.9 dB Modulation type **Uplink Scheme Enhancement of Enhancement of Power Efficiency** Connections Fast-OFDM Signal Waveform Adaptive Fast-OFDM can **Normalized CSI Magnitude** shift the occupied spectrum to a better channel portion based on SNR. SC-FDMA CSI at each sub-carrier is estimated to indicate SNR EVM= SC-FDMA -10.0 dB Fast-OFDM VR5 Channel Emulator Frequency (kHz) BPSK constellation comparison EVM= Fast-OFDM -17.7 dB Measured BER **Adaptive** EVM= Ideal Fast-OFDM. Same performance **Fast-OFDM** -20.9 dB Fast-OFDM in AWGN channel at Eb/No = 10 dB. but half bandwidth OFDM in AWGN channel at Eb/No = 10 dB. occupation Half-Sinc Signal Waveform Frequency (Hz) in phase ☐ Double data rate via packing two Half-Sinc signals **Enhancement of Data Rate** ☐ Robust to frequency offset due to the protection gap Sinc Waveform, 60% Frequency offset Sinc Waveform, 40% Frequency offset NB-IoT: OFDM Sinc Waveform, 20% Frequency offset (a) - - Sinc Waveform, ideal eNB-IoT: SEFDM Type-II Eb/No (dB) SE (bit/s/Hz) Sinc Waveform Data rate Parameters Half-Sinc Waveform NB-IoT 2 (QPSK) eNB-IoT 2.5 (QPSK) $1.25R_b$ (+25%) → eNB-IoT, SE=2.5, MF eNB-IoT, SE=2.5, SD (e) Half-Sinc NB-IoT 3 (8PSK) $1.5R_b$ (+50%) $1.5R_b$ (+50%) eNB-IoT 3 (QPSK)

 E_b/N_0 [dB]

-20 -100

Frequency (kHz)

-100

Frequency (kHz)

☐ Performance of QPSK modulated eNB-

IoT signals (a) α =0.8. (b) α =0.67 and

■ Non-orthogonal signal waveform is

improve IoT data rate!

◆ eNB-IoT, SE=3, MF ◆ eNB-IoT, SE=3, SD ■ NB-IoT, SE=3, MF/SD

 E_b/N_0 [dB]

QPSK, 8PSK modulated NB-IoT signals.

better than dense modulation formats to