Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Hierarchical Bandwidth Modulations for Flexible Backhaul Links – An Analysis
Date Submitted: 04 May 2022
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Re: Enhancements to the Physical Layer of IEEE 802.15.3d for Increased Data Rate and Coexistence/0125-01

Abstract: Discussion points for including a Hierarchical Bandwidth Modulation HBM PHY mode in the standard.

Purpose: For discussion and consideration to edit IEEE 802.15.3d Standard

IEEE P802.15.3ma Proposal Follow-up:
Hierarchical Bandwidth Modulations for Flexible Backhaul Links – An Analysis

Reminder: What is Hierarchical Bandwidth Modulation?

- Inspired by distance-dependent bandwidth of the THz channel, HBM uses a hierarchical constellation to introduce a hierarchy in signal bandwidth to optimally serve users at different distances

- Enable more than point-to-point links currently available for the standard with little additional overhead

High Res Bitstream: 101100010101001
Base Layer Bitstream: 010100010010011

| High Res Sym	High Res Sym	High Res Sym	High Res Sym	High Res Sym	High Res Sym	High Res Sym	High Res Sym
Base Layer QPSK Symbol		Base Layer QPSK Symbol		Base Layer QPSK Symbol		Base Layer QPSK Symbol	

amplitude

time
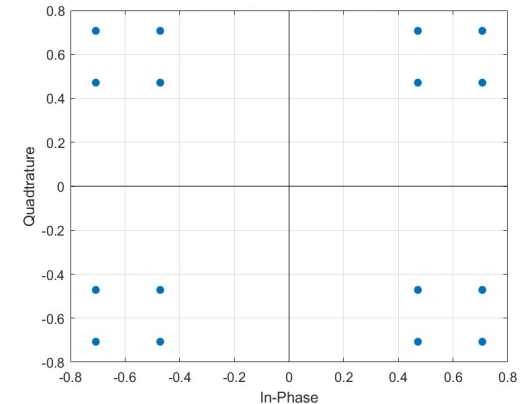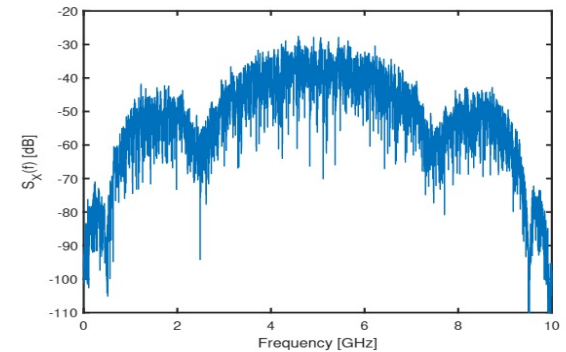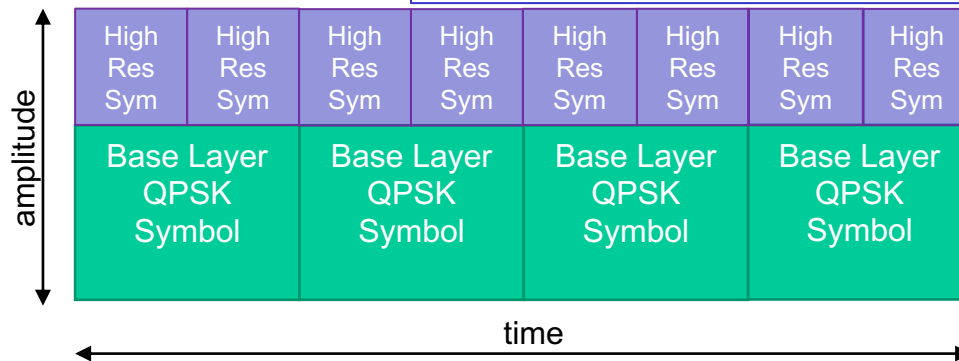
Hossain, Zahed, and Josep Miquel Jornet. "Hierarchical bandwidth modulation for ultra-broadband terahertz communications." *ICC 2019-2019 IEEE International Conference on Communications (ICC)*. IEEE, 2019.

Potential Application for Adaptable Point-to-Point Links Using HBM
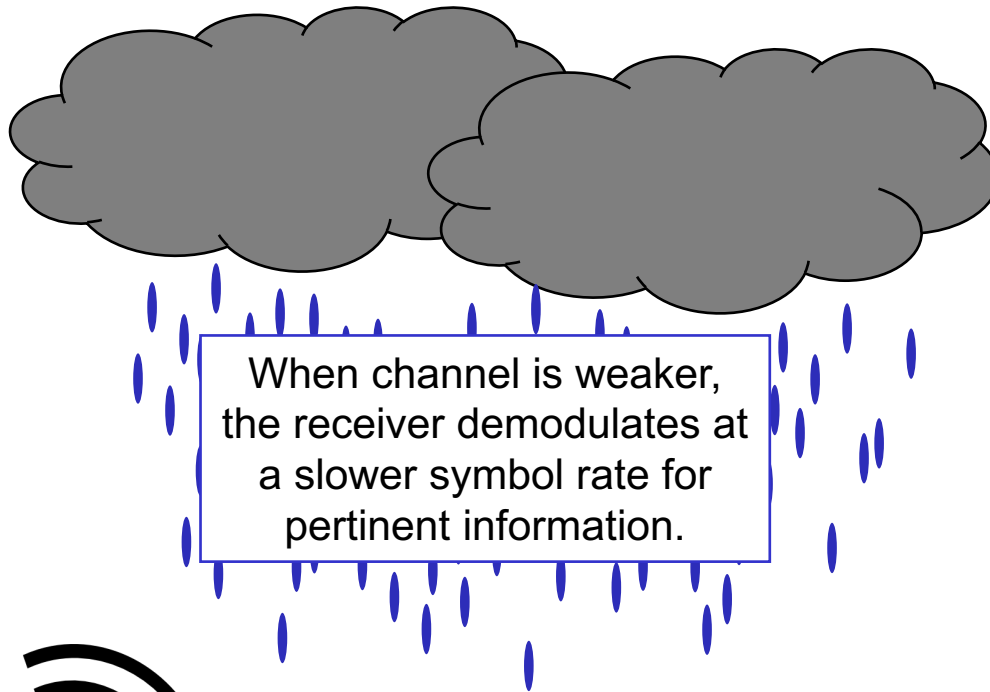
When channel is weaker, the receiver demodulates at a slower symbol rate for pertinent information.
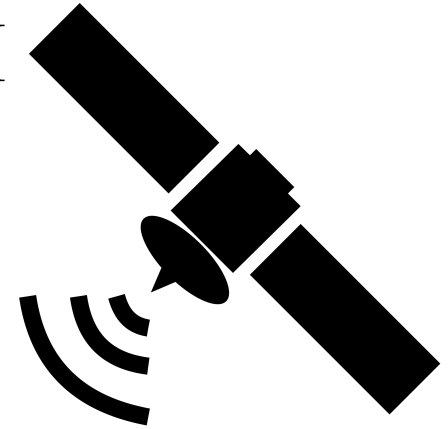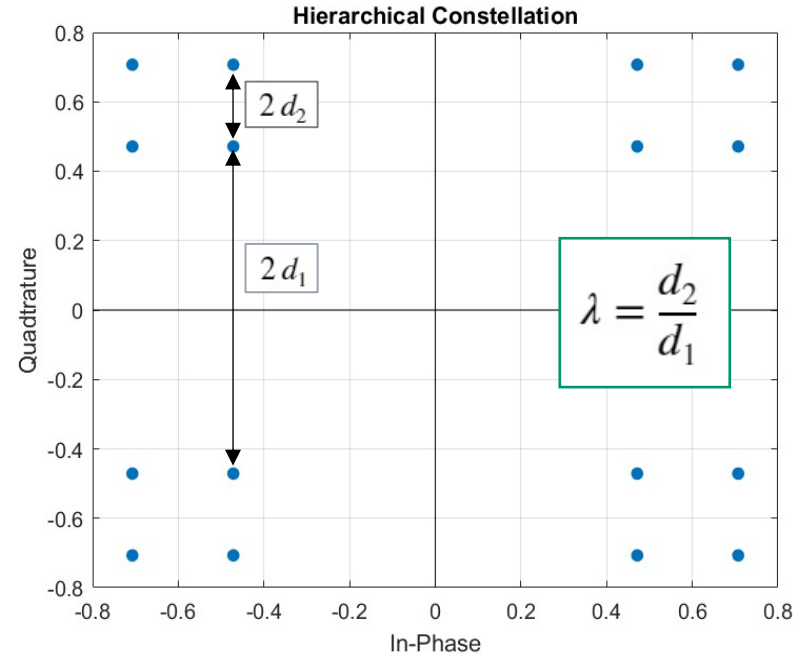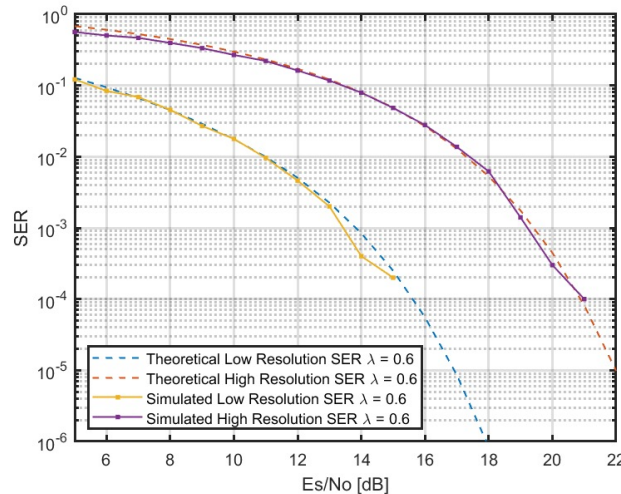
When channel is stronger, the receiver demodulates at faster symbol rate for high resolution.

Design Considerations for HBM

- Power allocated to each resolution
  - Depends heavily on transmission distances and observed Es/No values at the receivers

- Thresholds for switching resolutions at the receiver
  - Depends on the speed of channel variations

Hierarchical Constellation

$$\lambda = \frac{d_2}{d_1}$$

$$\text{SER}_{\text{LowRes}} = Q\left(\sqrt{\frac{\frac{E'_s}{N_0}}{1 + 2\lambda + 2\lambda^2}}\right) + Q\left((1 + 2\lambda)\sqrt{\frac{\frac{E'_s}{N_0}}{1 + 2\lambda + 2\lambda^2}}\right)$$

$$\text{SER}_{\text{HighRes}} = 2\,Q\left(\lambda\,\sqrt{\frac{\frac{E_s}{N_0}}{1 + 2\lambda + 2\lambda^2}}\right) + Q\left(\sqrt{\frac{\frac{E_s}{N_0}}{1 + 2\lambda + 2\lambda^2}}\right)$$

Duschia Bodet, Priyangshu Sen, Zahed Hossain, Ngwe Thawdar, and Josep Miquel Jornet. "Hierarchical bandwidth modulation for ultra-broadband communications in the Terahertz Band." submitted for journal publication 2022.

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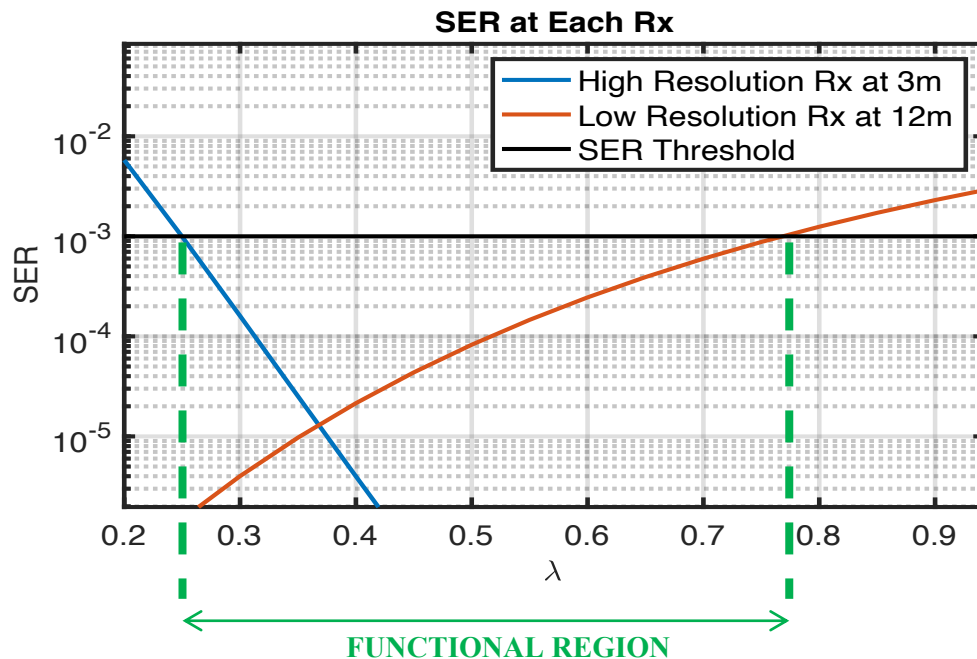 - Depends on the speed of channel variations

SER at Each Rx

λ	LR SER	HR SER
0.2	$8.33 * 10^{-4}$	0.0028
0.4	$< 4.17 * 10^{-4}$	$1 * 10^{-4}$
0.6	$< 8 * 10^{-5}$	$4 * 10^{-5}$
0.8	0.005	$2 * 10^{-4}$

Experimental Validation

FUNCTIONAL REGION

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Function of how quickly channel fluctuates, and frame duration (establishes a buffer)

Switching from Low to High

$$\frac{E_s}{N_0}_{LowHighTh}[dB] = \frac{E_s}{N_0}_{ThHigh}[dB] + \alpha[dB] + \beta[dB]$$

Switching from High to Low

$$\frac{E_s}{N_0}_{HighLowTh}[dB] = \frac{E_s}{N_0}_{ThHigh}[dB] + \alpha[dB]$$

Corresponds to SER Threshold (absolute threshold)

Function of how quickly channel fluctuates, frame duration, and number of consecutive frames that should demodulate with same resolution (establishes a transition region for less flip-flopping)

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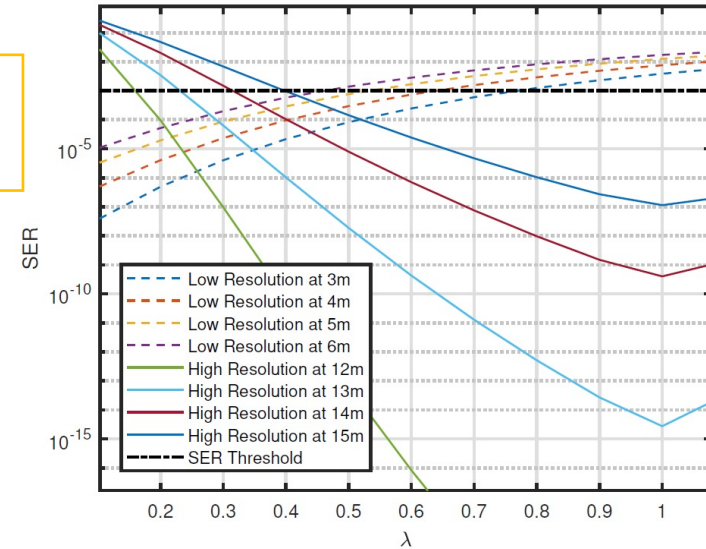
Considerations for HBM in 802.15.3d

- Offers more receiver flexibility in fluctuating channels
  - Currently in the standard, the pairnet would need to switch channels to operate at a different bandwidth (i.e. none of the established channels have the same center frequency)
- Eliminates the need for back-and-forth signaling in the event of a bad channel while achieving same maximum data rates as THz-SC PHY mode