ECE 463: Digital Communications Lab.

Lecture 11: IoT I: LPWAN

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Previous Lecture:

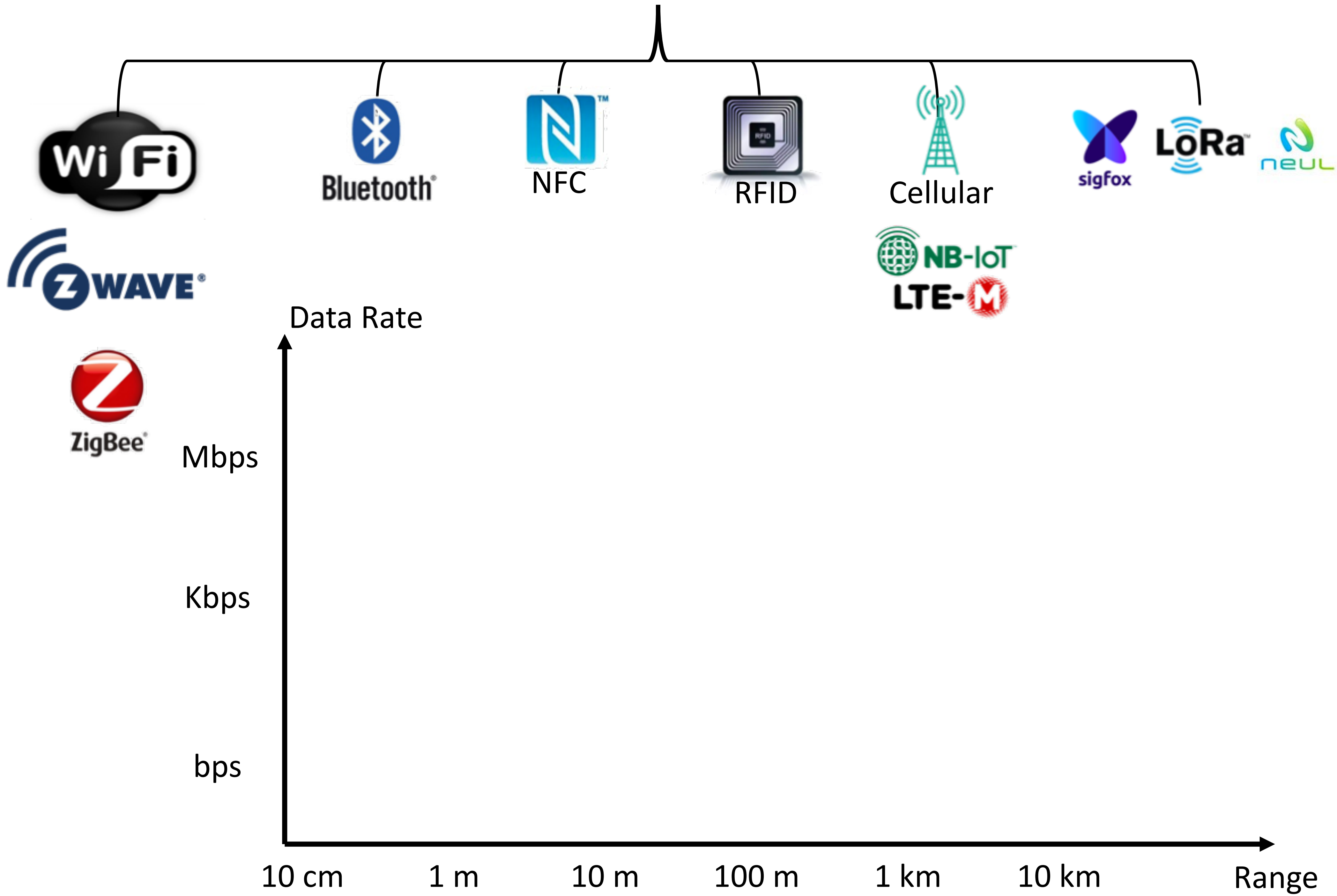
- ✓ OFDM Time Synchronization
- ✓ OFDM Channel Estimation & Correction
- ✓ OFDM Phase Tracking

This Lecture:

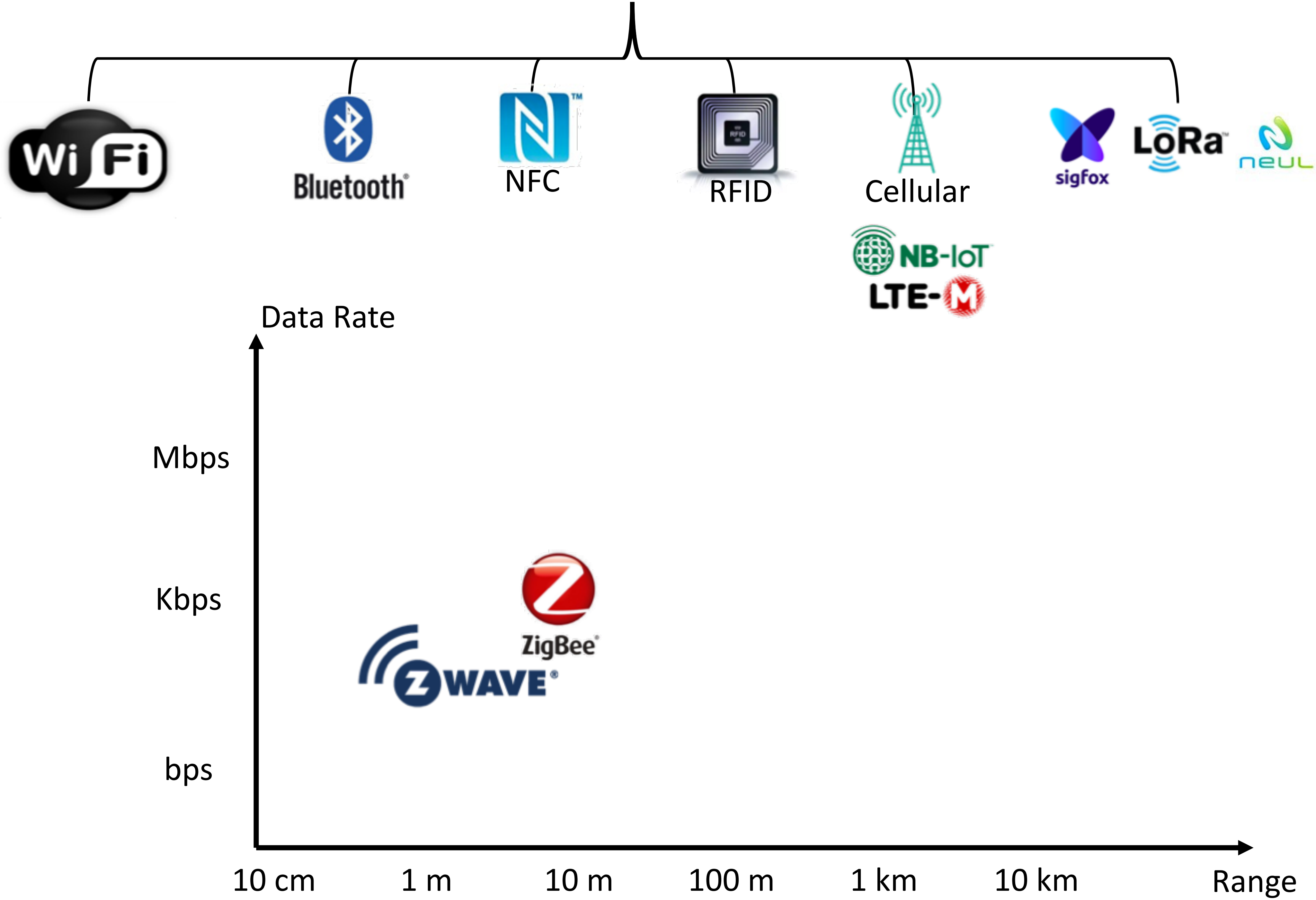
- ❑ IoT Intro.
- ❑ Spread Spectrum
- ❑ Low Power Wide Area Networks

IoT Technologies

IoT Technologies



IoT Technologies



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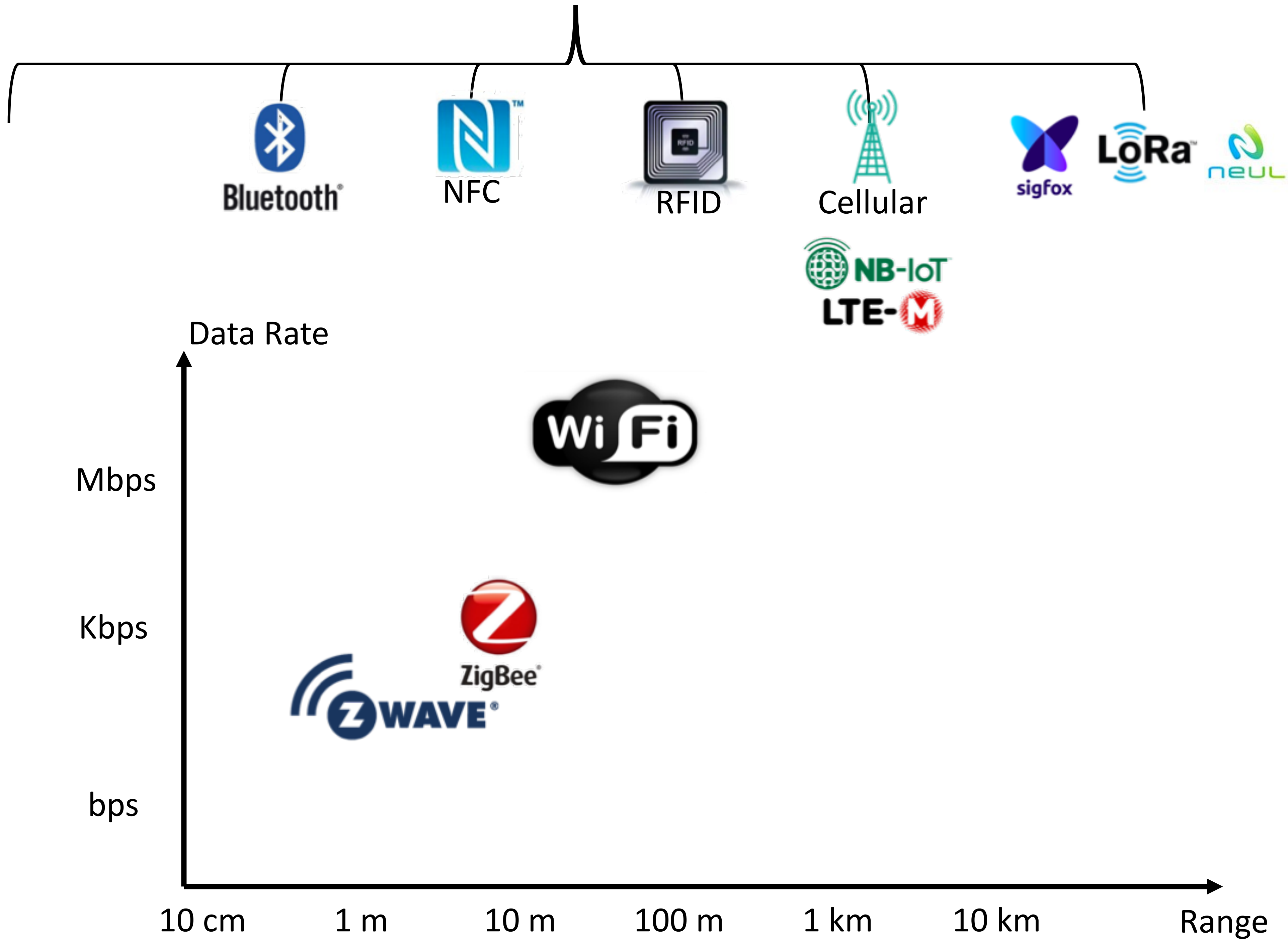

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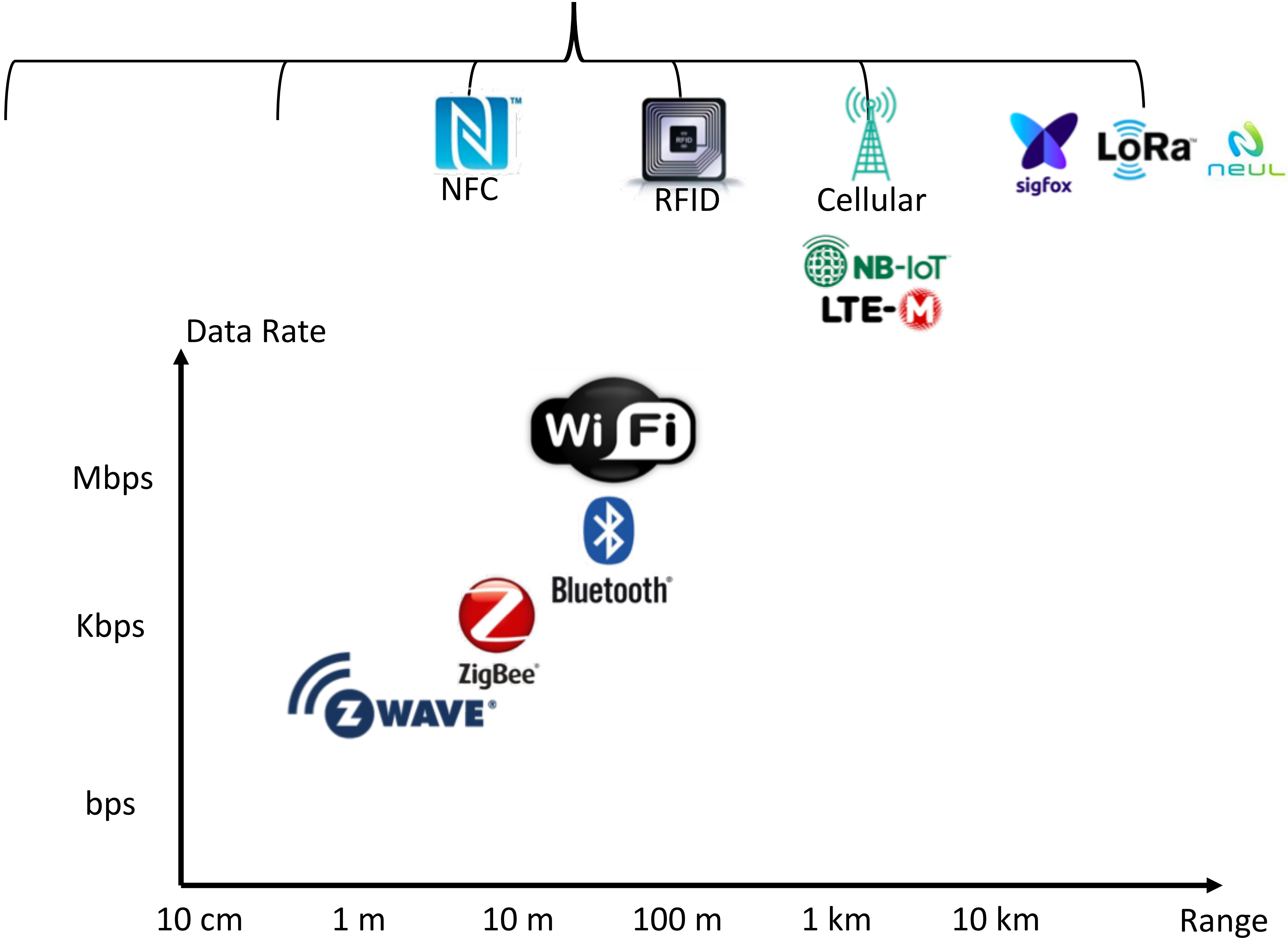
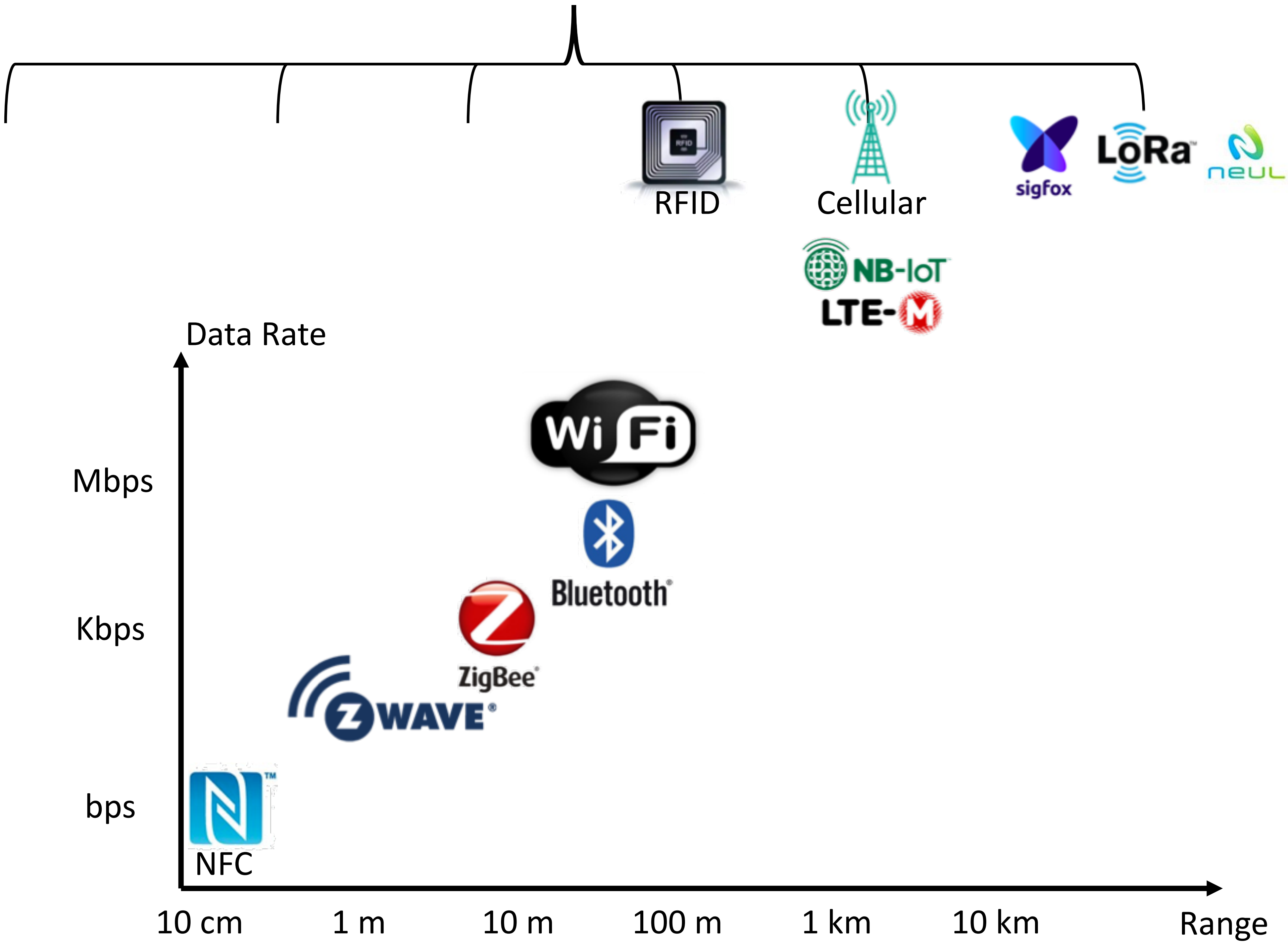
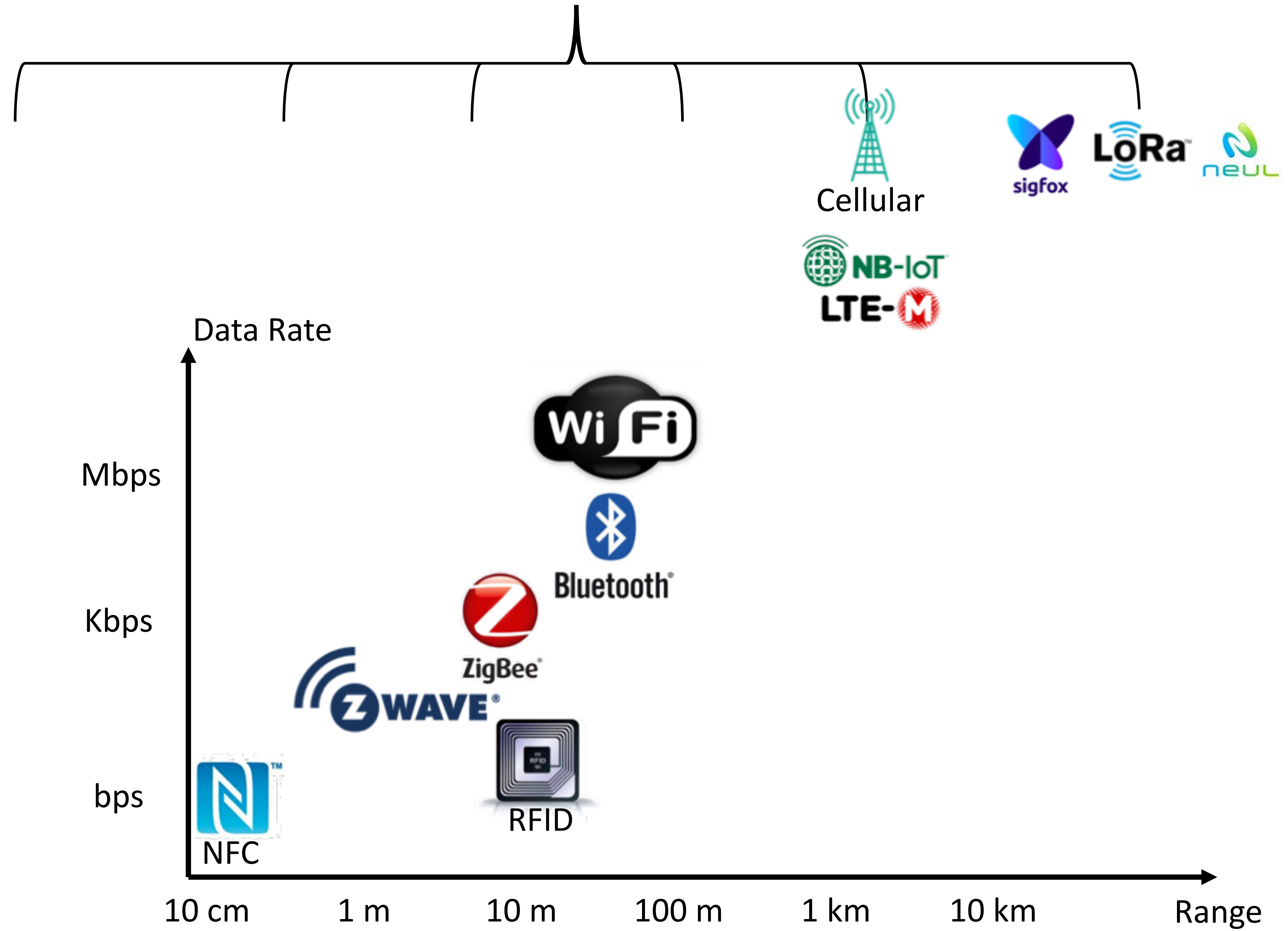


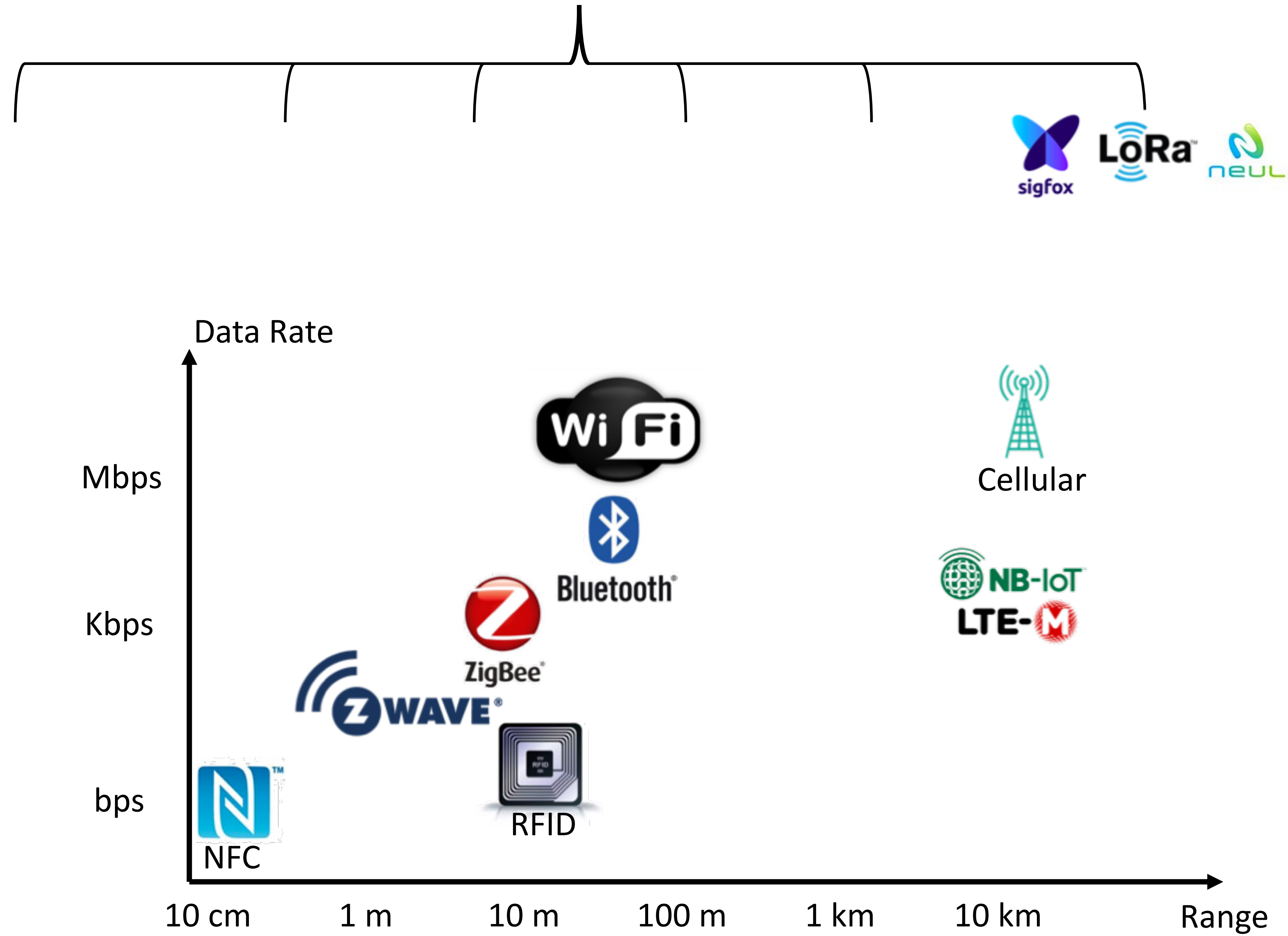
IoT Technologies



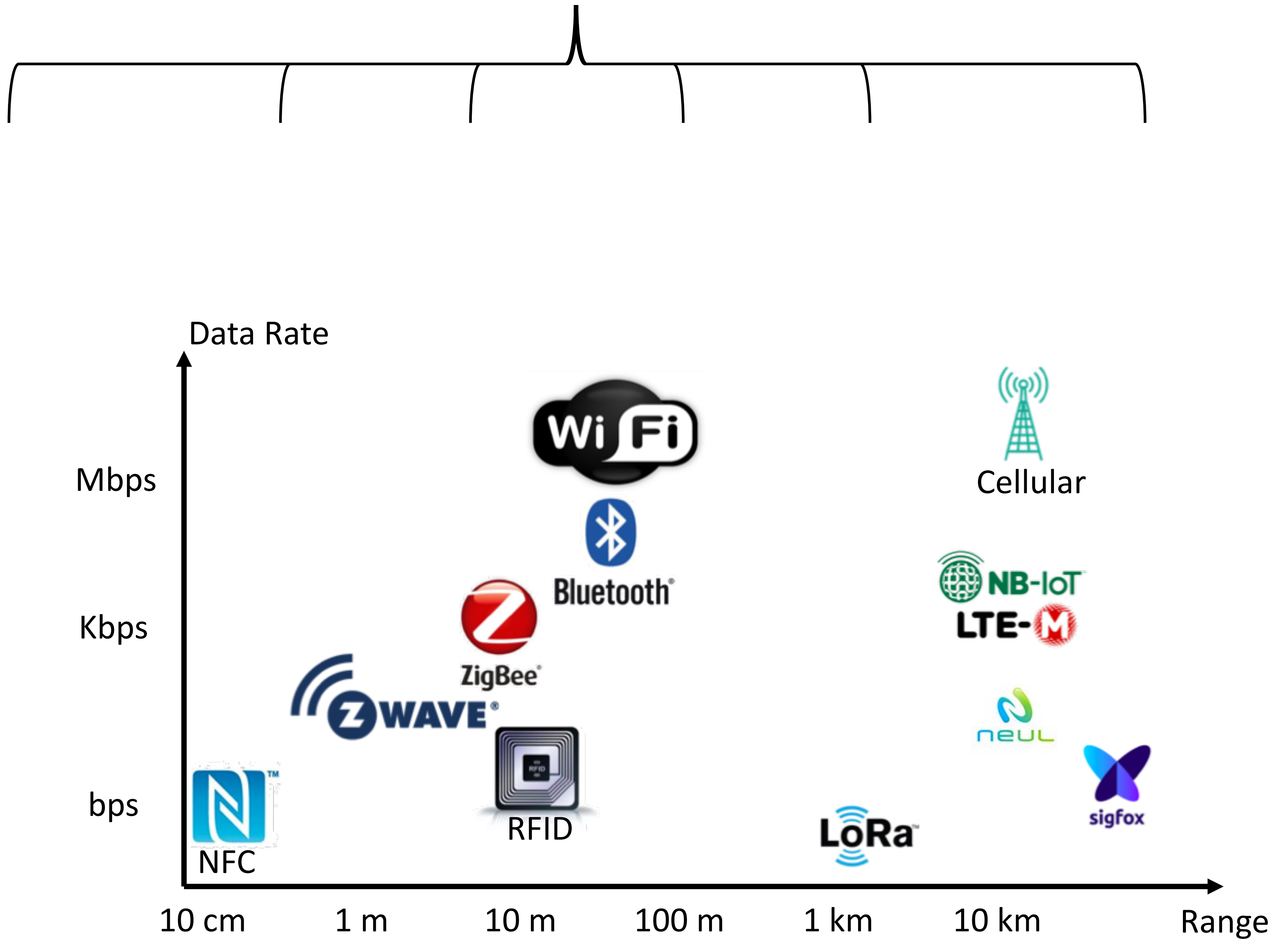
IoT Technologies



IoT Technologies

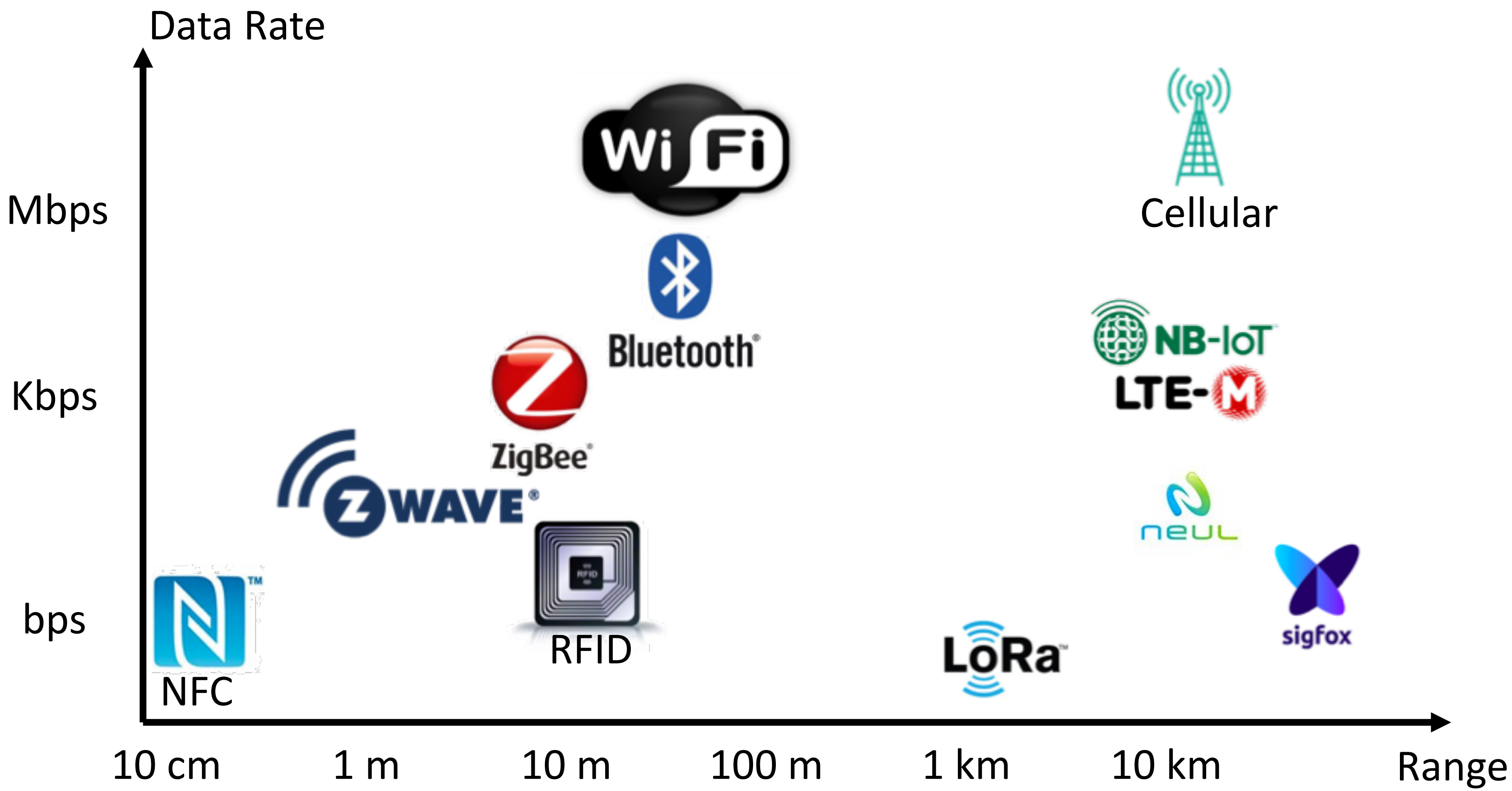


IoT Technologies



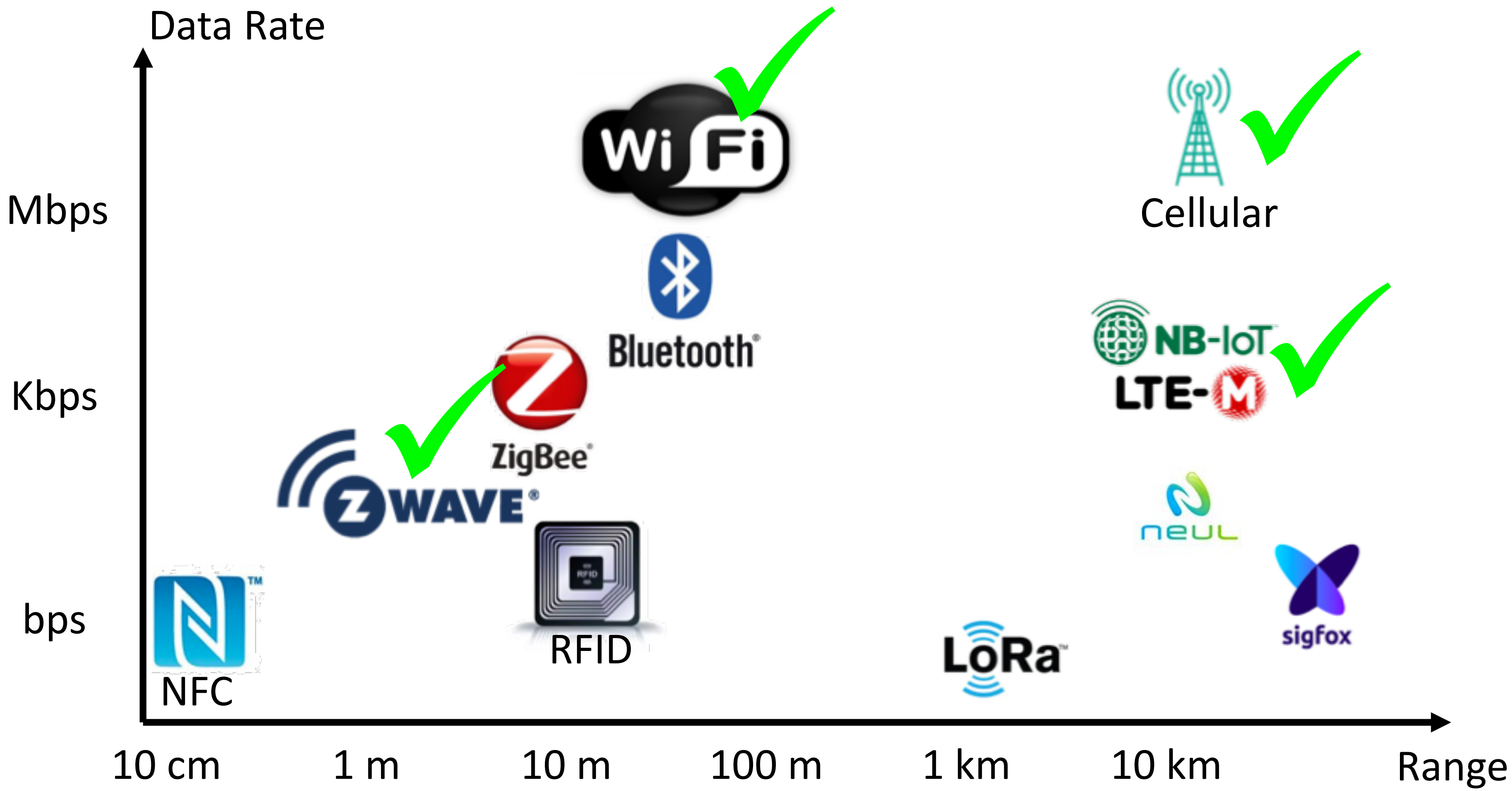
IoT Technologies

Metrics to consider: Data Rate, Range,



IoT Technologies

Metrics to consider: Data Rate, Range, Power (batter life), Cost



IoT: Low Power Wide Area Networks

LoRa™ neul sigfox

- Low power: battery lasts 5-10 years
- Low cost: $10-$20
- High range: 1 - 10 km
- Low Data rates: 100bps – 250 Kbps

IoT: Low Power Wide Area Networks

LoRa™

neul

sigfox

IoT: Low Power Wide Area Networks

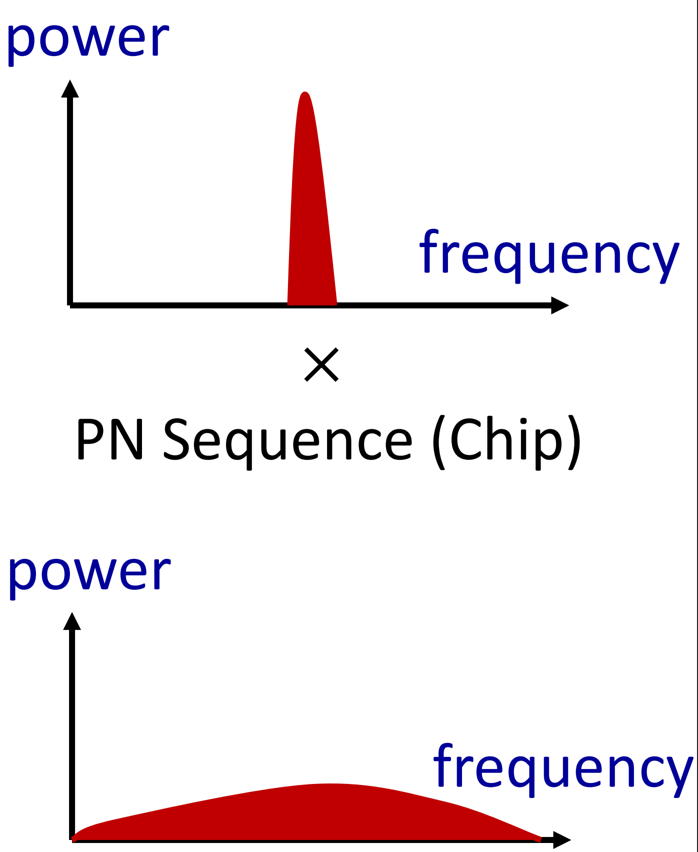
LoRa™ neul sigfox

Digital Communication Technology:

CCS: Chirp Spread Spectrum

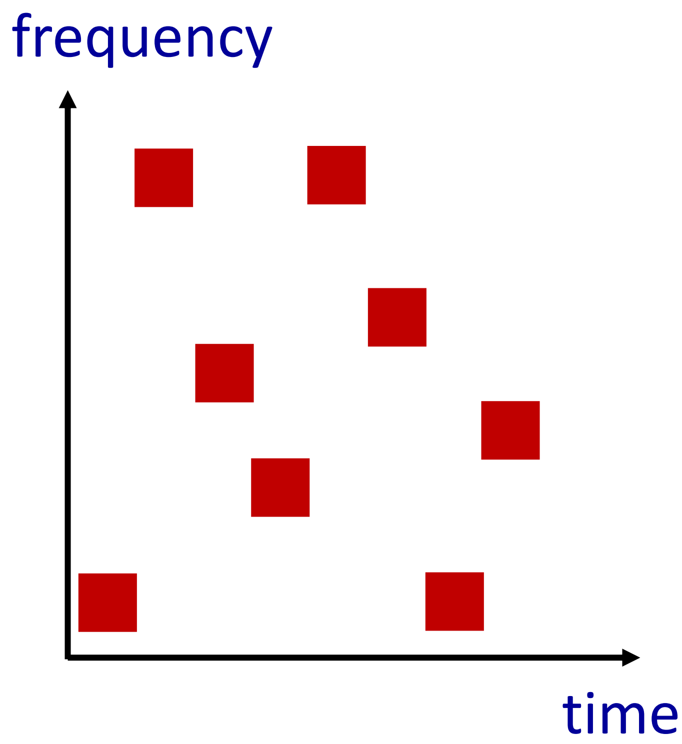
Spread Spectrum Technology

DSSS:
Direct Sequence Spread spectrum



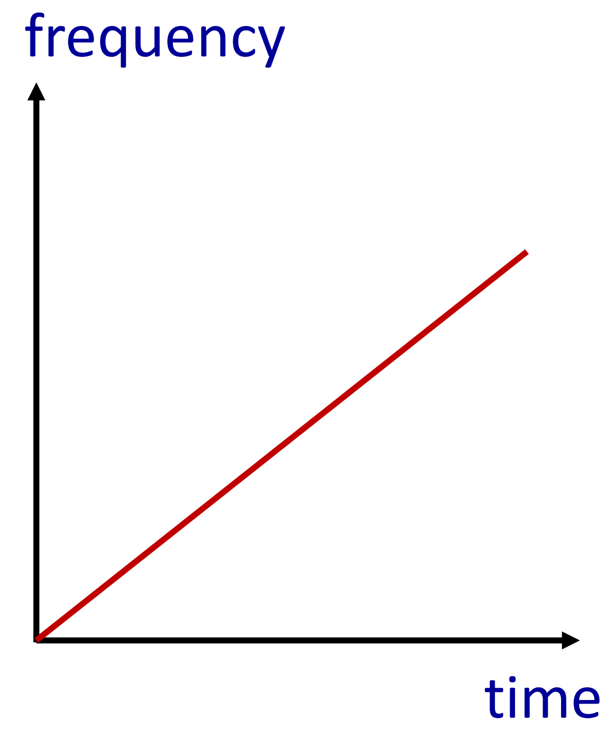
3G, 802.11b, GPS, Military

FHSS:
Frequency Hopping Spread spectrum



Bluetooth, Military

CSS:
Chirp Spread Spectrum



LPWAN, Radar

Spread Spectrum Technology

DSSS: Direct Sequence Spread spectrum	FHSS: Frequency Hopping Spread spectrum	CSS: Chirp Spread Spectrum
3G, 802.11b, GPS, Military	Bluetooth, Military	LPWAN, Radar

Spread Spectrum Technology

DSSS: Direct Sequence Spread spectrum	FHSS: Frequency Hopping Spread spectrum	CSS: Chirp Spread Spectrum
3G, 802.11b, GPS, Military	Bluetooth, Military	LPWAN, Radar

- Robust to jamming and interference
- Robust to frequency selective fading
- Secure (Military Applications)
- Enables multi-user

CSS: Chirp Spread Spectrum

- Chirp is signal that continuously sweeps frequency with time.
- For linear chirp: $f(t) = \alpha t + f_0$

$$\phi(t) = \int 2\pi f \, dt \; = 2\pi \frac{\alpha}{2} t^2 + 2\pi f_0 t + \phi_0$$

$$s(t) = \exp\left(j2\pi \frac{\alpha}{2} t^2 + j2\pi f_0 t + j\phi_0\right)$$

CSS: Chirp Spread Spectrum

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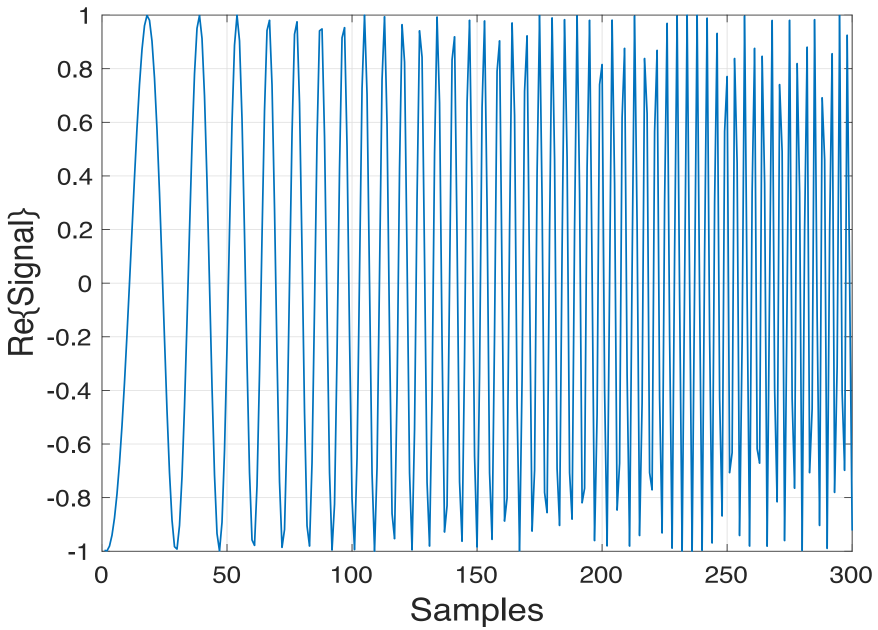
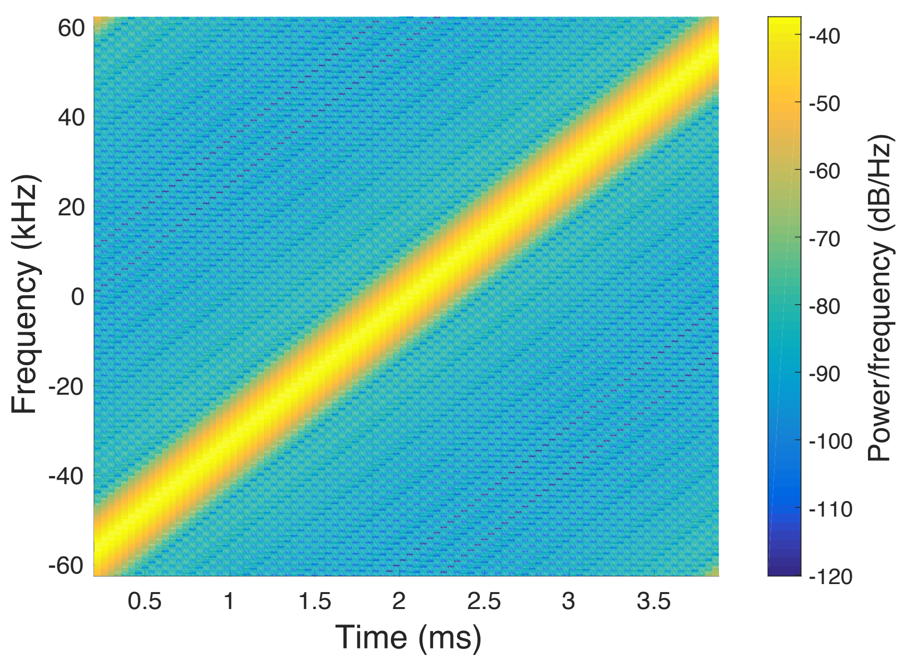
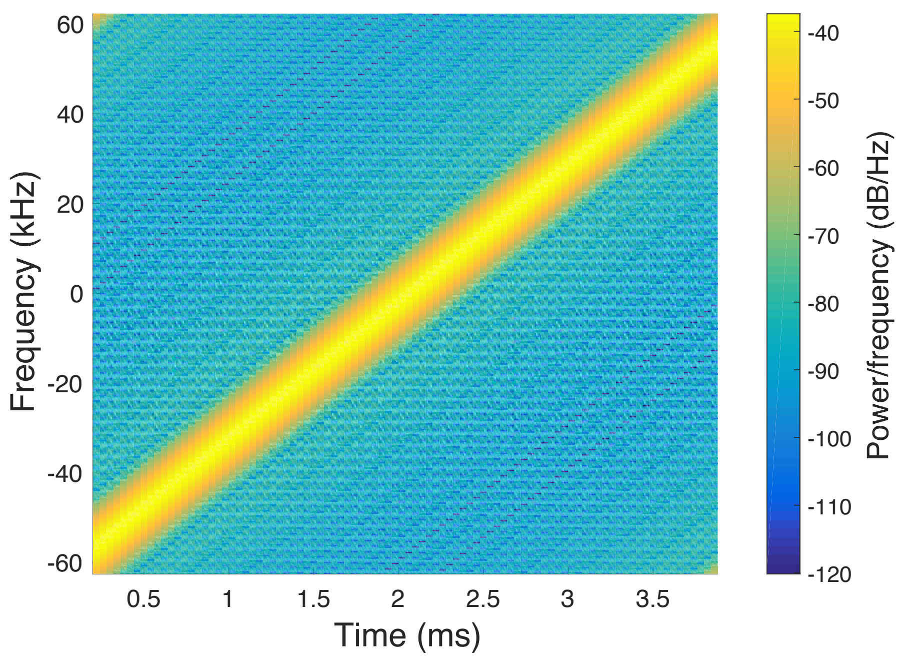




CSS: Chirp Spread Spectrum

- For linear chirp: $f(t) = \alpha t + f_0$

$$s(t) = \exp\left(j2\pi \frac{\alpha}{2} t^2 + j2\pi f_0 t + j\phi_0\right)$$

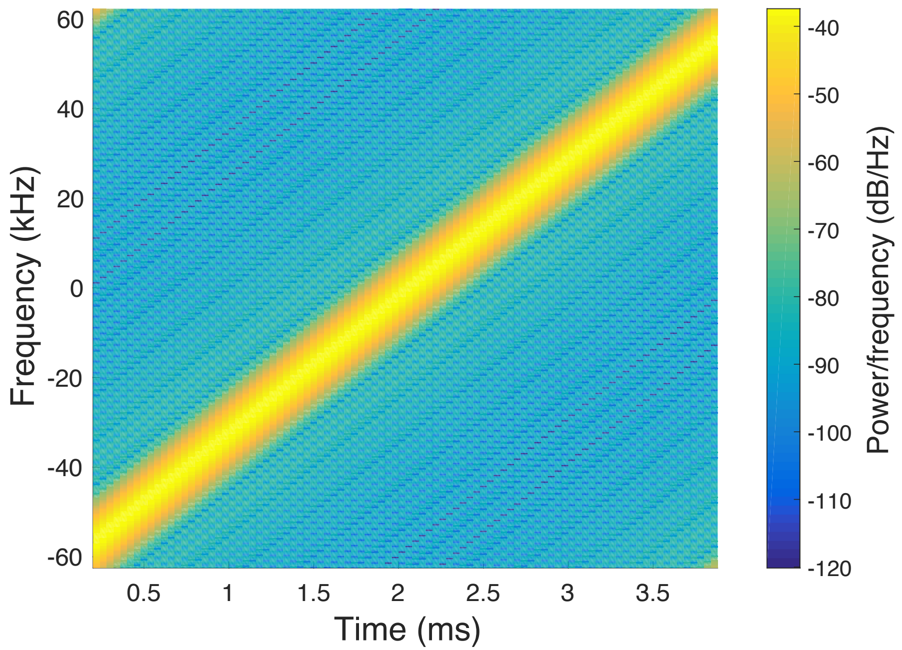


- Sweep from $-\frac{B}{2}$ to $+\frac{B}{2}$
- Sweep time is: T_s
- Sweep slope is: $\alpha = \frac{B}{T_s}$

CSS: Chirp Spread Spectrum

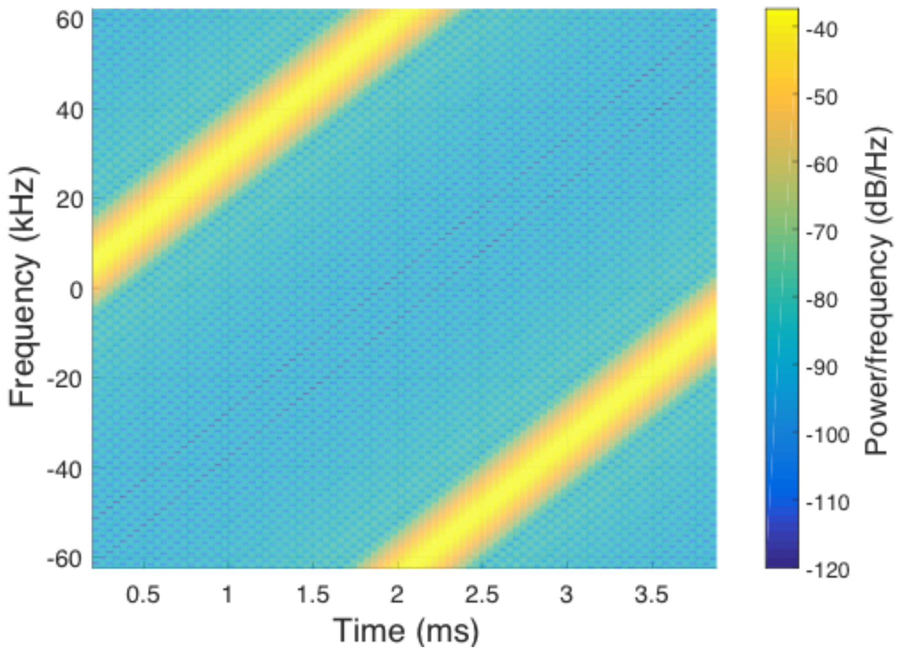
- Each symbol is sent as 1 chirp.
- Symbol time = Sweep time = T_s.
- Encode bits at sweep start.

bit = '0'



$$f(t) = \alpha t - B/2$$

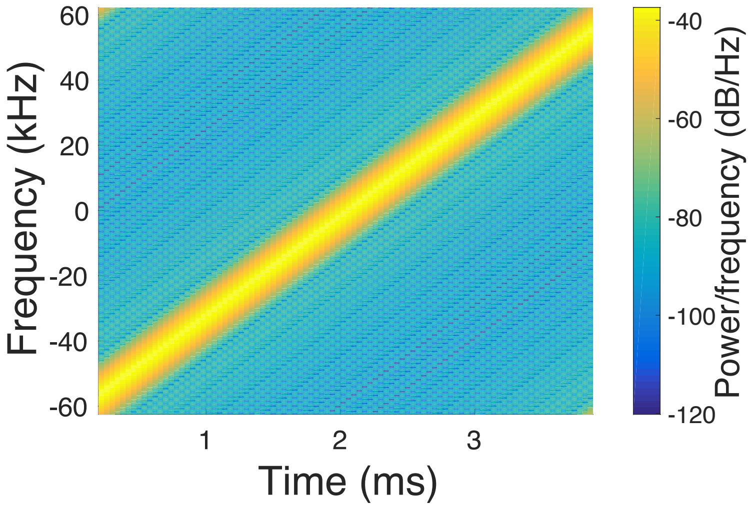
bit = '1'



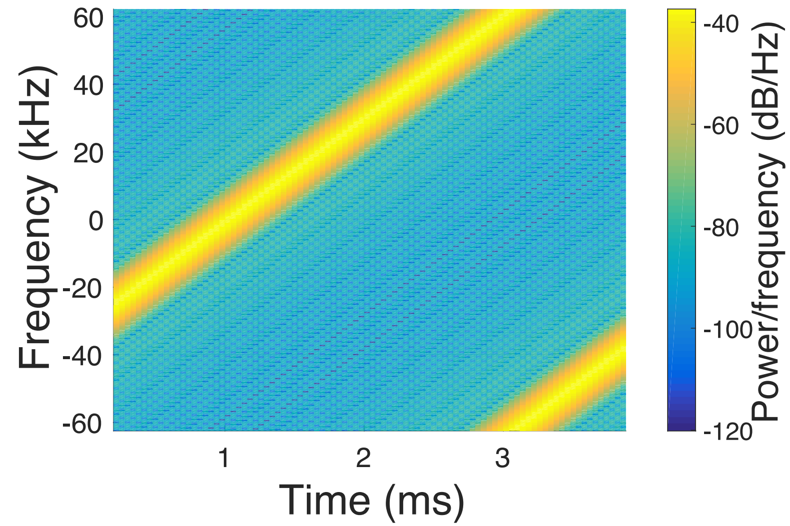
$$f(t) = \alpha t \mod B$$

CSS: Chirp Spread Spectrum

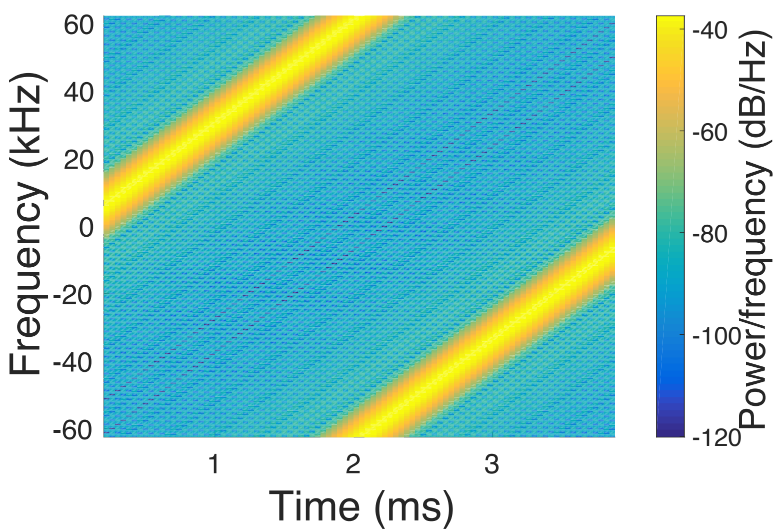
bits = ‘00’



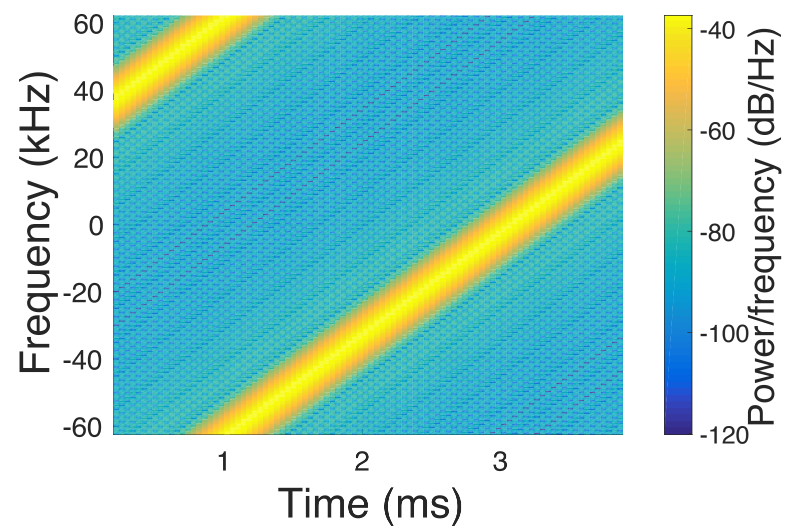
bits = ‘01’



bits = ‘10’



bits = ‘11’



CSS: Chirp Spread Spectrum

In general, to encode n bits per symbol: 2^n shifts

But, How do we decode?

But, How do we decode?

At TX:

bit = '0' $$s_0(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 + j2\pi\frac{B}{2}t + j\phi_0\right)$$

bit = '1' $$s_1(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 + j\phi_0\right)$$

At RX:

$$y(t) \times s_0^*(t) = y(t)\exp\left(-j2\pi\frac{\alpha}{2}t^2 - j2\pi\frac{B}{2}t\right)$$

bit = '0' $$= \exp(j\phi_0)$$

FFT

Pulse at $f = 0$

bit = '1' $$= \exp\left(-j2\pi\frac{B}{2}t + j\phi_0\right)$$

Pulse at $f = \frac{B}{2}$

But, How do we decode?

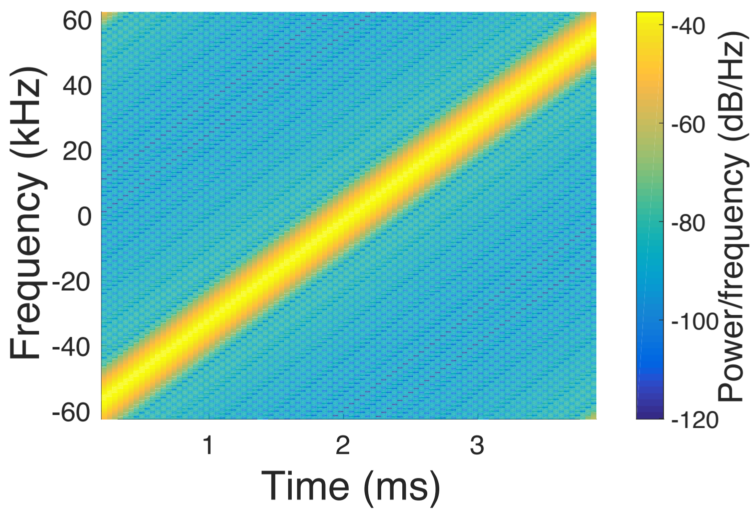
(1) Demodulate by multiplying with $s_0^*(t)$

(2) Take and FFT over symbol time

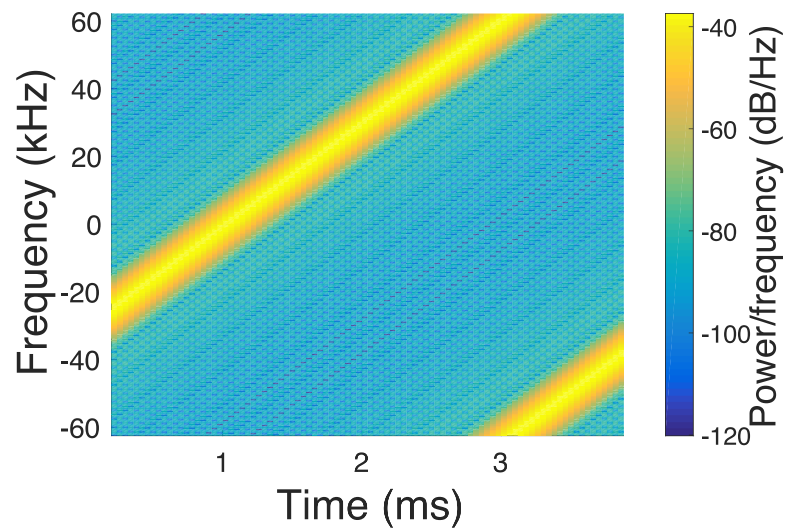
(3) Find position of the peak

But, How do we decode?

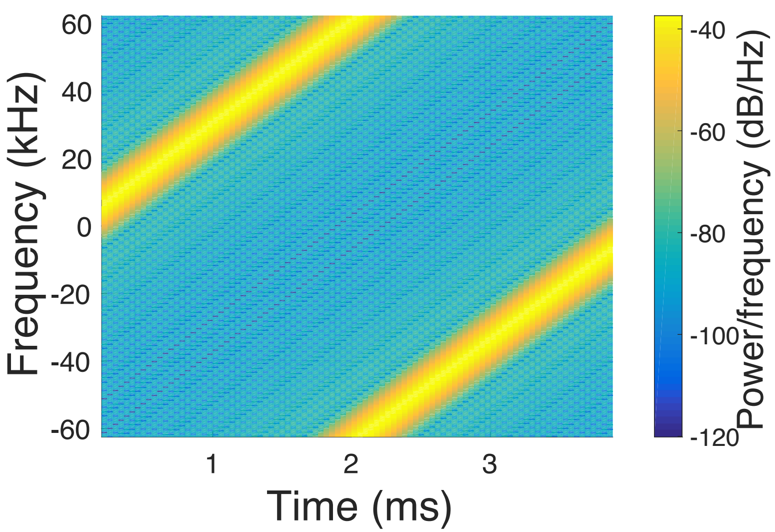
bits = ‘00’



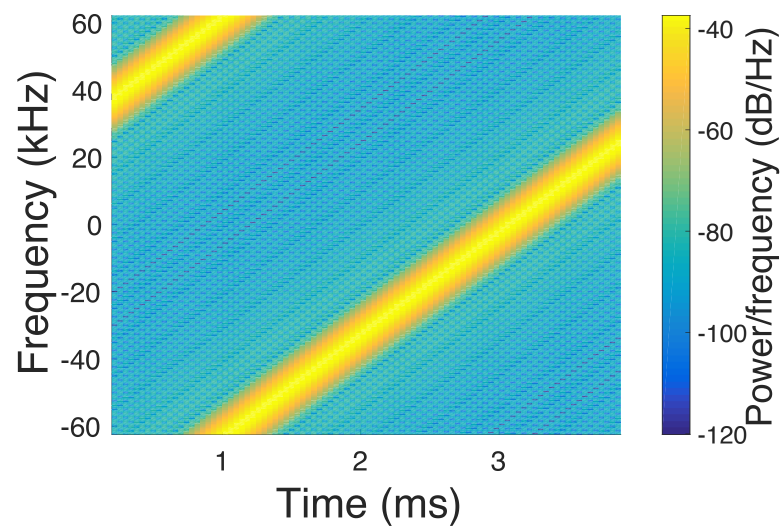
bits = ‘01’



bits = ‘10’

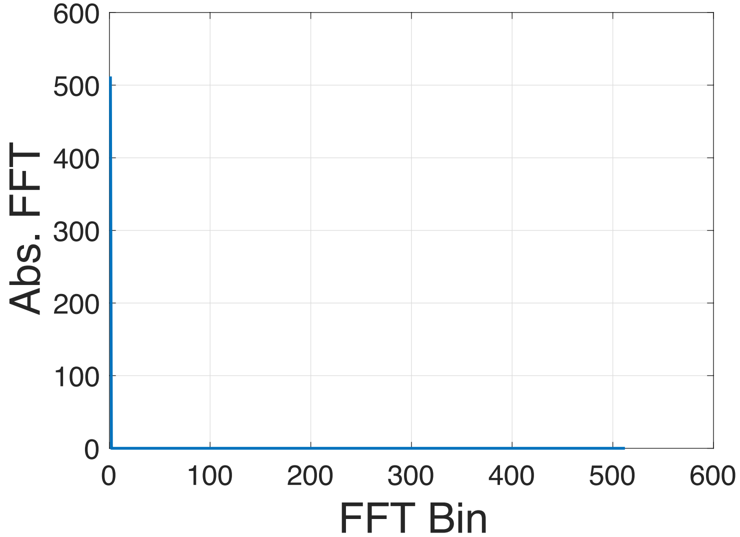


bits = ‘11’

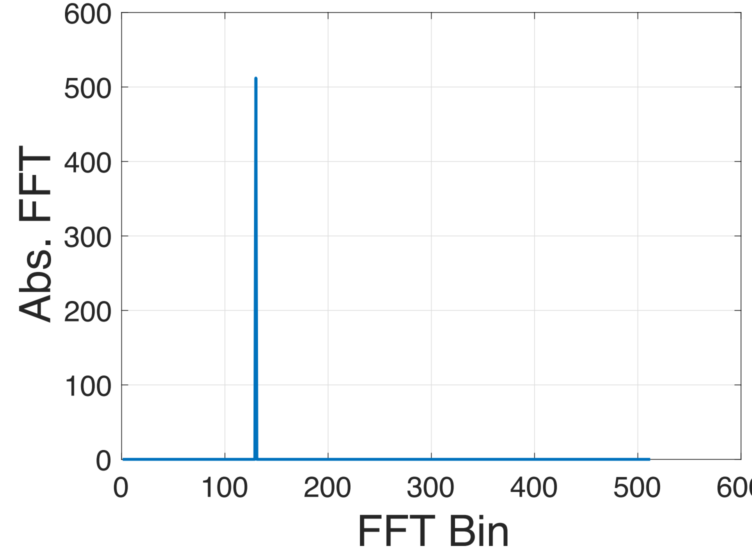


But, How do we decode?

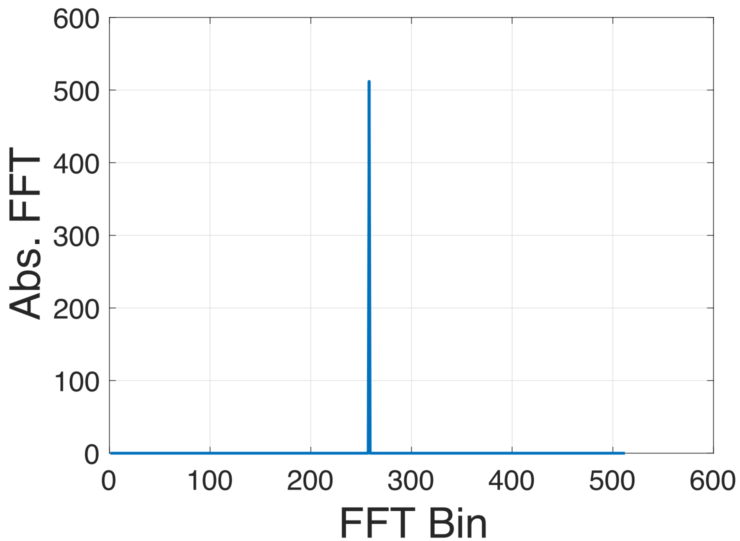
bits = ‘00’



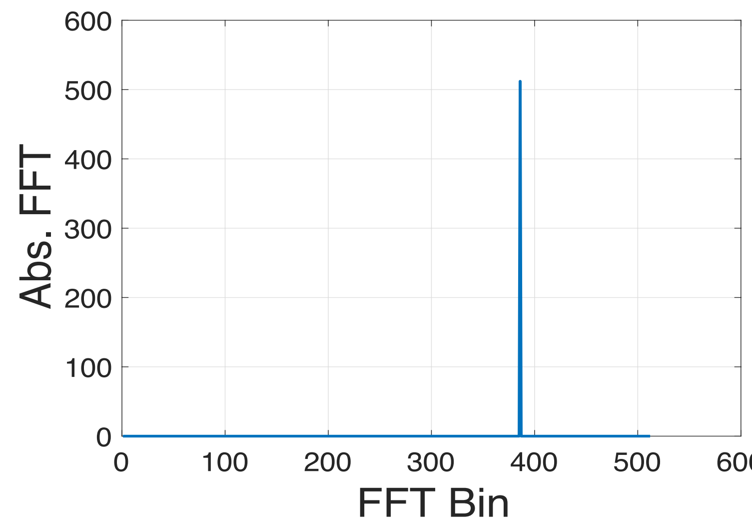
bits = ‘01’



bits = ‘10’



bits = ‘11’



What about the wireless channel?

LPWAN use low bandwidth (120kHz)

Narrow band channel

$$y(t) = h\, s_0(t) \times s_0^*(t)$$

bit = '0' $= h \exp(j\phi)$ → FFT → Pulse at $f = 0$

bit = '1' $= h \exp\left(j2\pi \frac{B}{2} t + j\phi\right)$ → FFT → Pulse at $f = \frac{B}{2}$

Channel changes amplitude & phase but not position of pulse

→ Can decode without correcting for channel

What about CFO & Sampling offset?

At TX: $s(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 + j2\pi f_0 t + j\phi_0\right)$

At RX: $s(t)\times \tilde{s}^*(t)$

$$= s(t)\times \exp\left(-j2\pi\frac{\alpha}{2}(t-\tau)^2 - j2\pi(f_0+\Delta f_c)(t-\tau)\right)$$

$$= \exp\left(j2\pi\alpha t\tau - j2\pi\frac{\alpha}{2}\tau^2 - j2\pi\Delta f_c t + j2\pi(f_0+\Delta f_c)\tau + j\phi_0\right)$$

What about CFO & Sampling offset?

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$$= \exp\left(j2\pi\alpha t\tau - j2\pi\frac{\alpha}{2}\tau^2 - j2\pi\Delta f_c t + j2\pi(f_0 + \Delta f_c)\tau + j\phi_0\right)$$

$$= \exp(j2\pi\alpha t\tau - j2\pi\Delta f_c t + j\phi')$$

What about CFO & Sampling offset?

At TX: $s(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 + j2\pi f_0 t + j\phi_0\right)$

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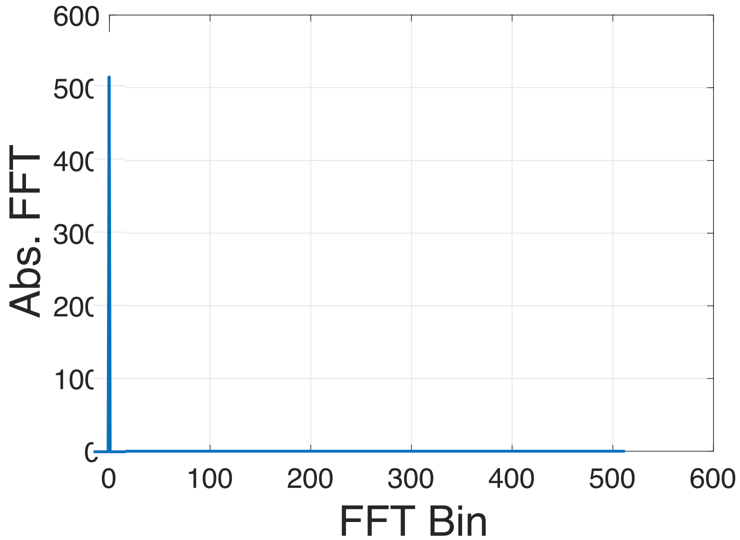
$$= \exp(j2\pi\alpha t\tau - j2\pi\Delta f_c t + j\phi') = \exp(j2\pi(\alpha\tau - \Delta f_c)t + j\phi')$$

FFT → Pulse at $f = -\alpha\tau + \Delta f_c$

What about CFO & Sampling offset?

bits = ‘00’



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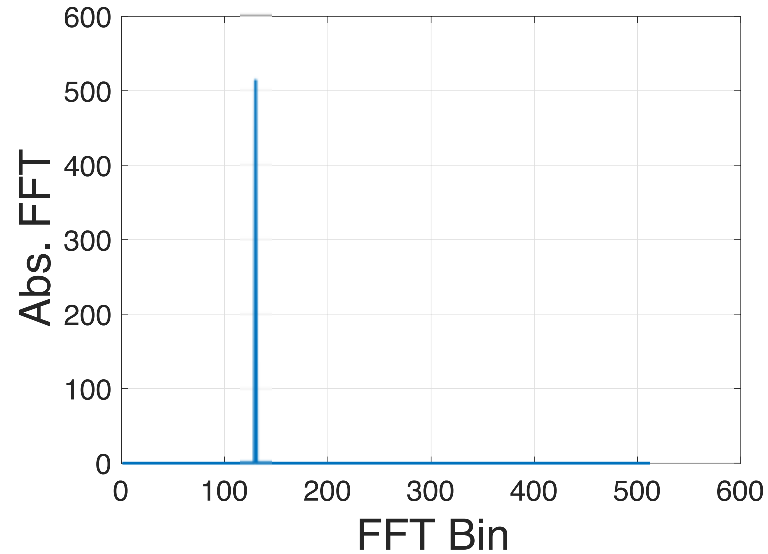
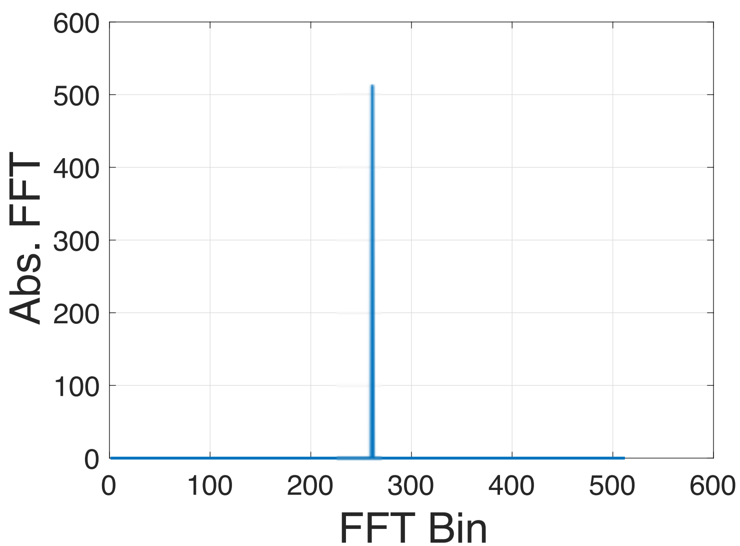
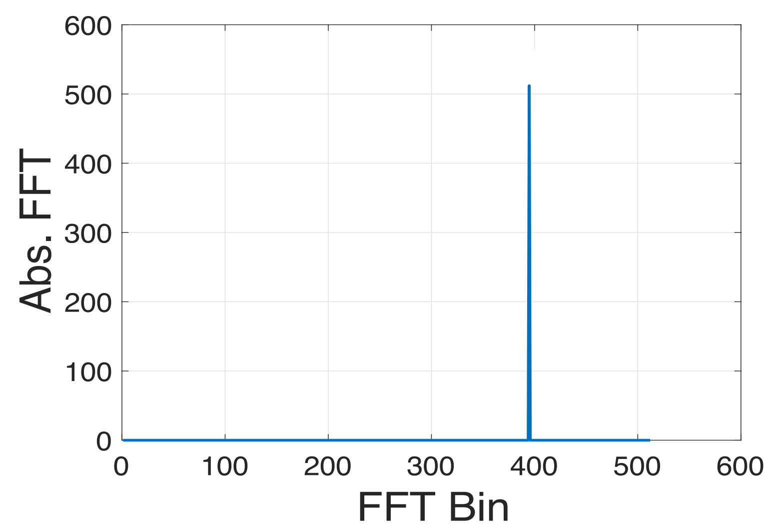


bits = ‘10’

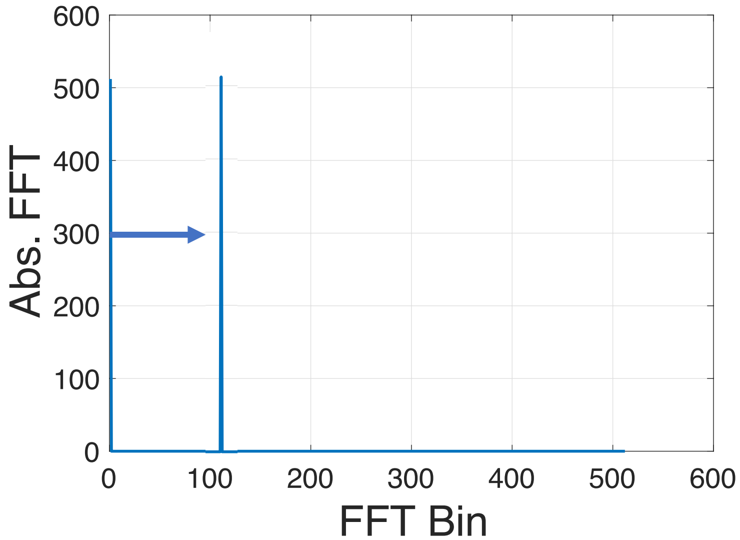


bits = ‘11’

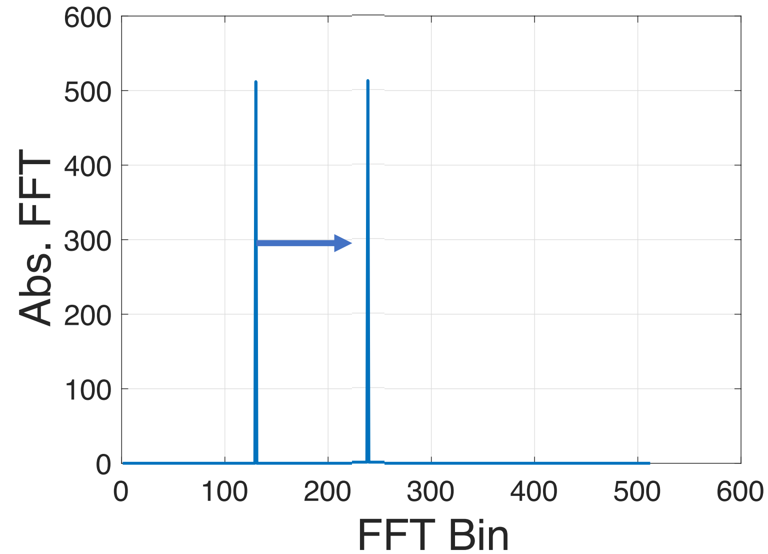


What about CFO & Sampling offset?

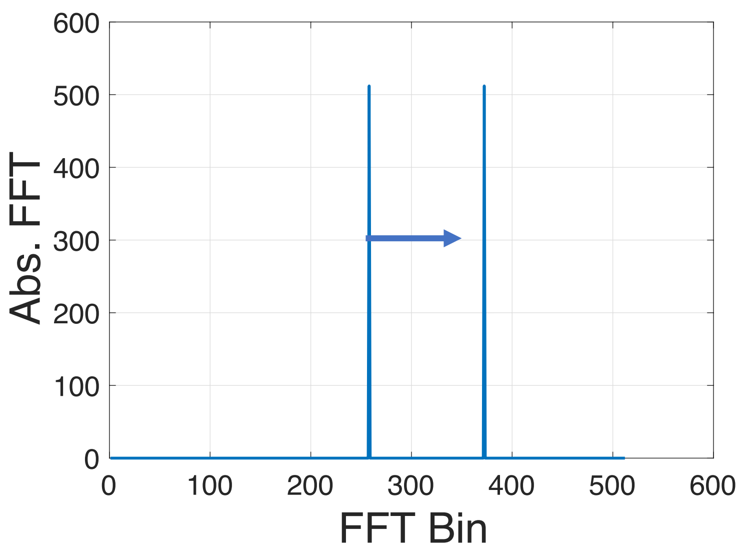
bits = ‘00’



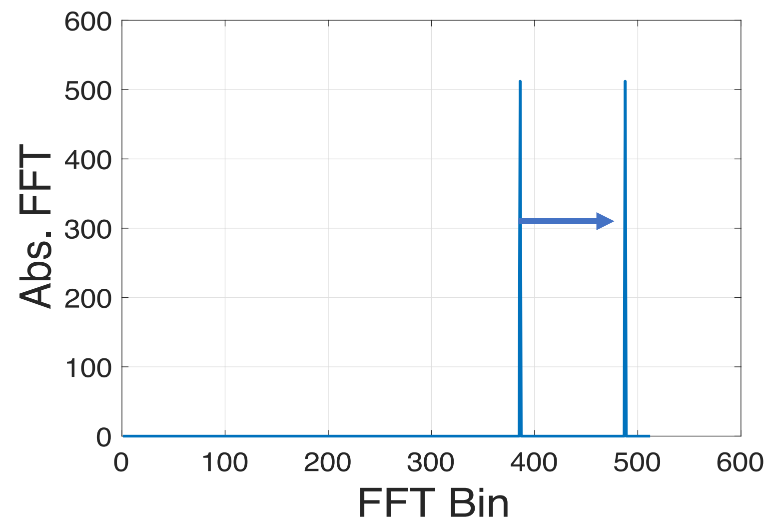
bits = ‘01’



bits = ‘10’



bits = ‘11’



What about CFO & Sampling offset?

CFO & STO shift the peaks at the output of FFT which prevent us from decoding correct.

Both CFO & STO have the same effect because frequency and time are linearly related.

$$f(t) = \alpha t + f_0$$

$$f(t) = \alpha(t - \tau) + f_0 + \Delta f_c$$

$$= \alpha t + f_0 + \alpha\tau + \Delta f_c$$

$$= \alpha(t - \tau + \Delta f_c/\alpha) + f_0$$

What about CFO & Sampling offset?

CFO & STO shift the peaks at the output of FFT which prevent us from decoding correct.

Send preamble!

Known bits → detect shit in peak due to CFO and STO & correct for it.

Do we need to worry about residual CFO & SFO?

LoRaWAN™: Packet Structure