**Introduction of LoRa & Challenges**

**LoRa & Chirp Spread Spectrum**
- LoRa attracts attention as one of the key wireless technology for IoT owing to its capability to cover a wide area with low power consumption.
- LoRa uses ‘Chirp Spread Spectrum (CSS)’ for low-power and long-range communication.
- CSS embeds data into an up-chirp with frequency shift, and extracts using a down-chirp. (de-chirp)
  - Up-chirp: a chunk of frequency that linearly increases over time
  - Down-chirp: a chunk of frequency that linearly decreases over time

**Decoding Failure in Collision**
- CSS’s modulation and demodulation includes the following step.
  1. Start frequency index of an upchirp represents a data symbol.
  2. Transmitter sets the start frequency according to the data and transmits.
  3. Receiver multiplies received signal with a downchirp. (de-chirp)
  4. Fast Fourier Transform (FFT) is applied to the de-chirped signal.
  5. Index of FFT bin peak represents a demodulated data symbol.
- Since a chirp consecutively increases frequency, a collision of two chirps leads to less distinction in FFT bin height between superposed symbols.
- Ambiguity will be more severe as the collision offset (Δt) gets narrower.

**FH-CSS: Frequency Hopped Chirp Spread Spectrum**

**Energy Scattering Effect**
- Proposed Scheme, FH-CSS, leverages the observation that the energy of de-chirped signal spreads out if chirps are not a counter part of each other.

**Aligned scenario**

**Misaligned scenario**

- A misaligned chirp has less FFT bin height while the aligned chirp peaks.
  → FH-CSS can resolve collisions without additional signal processing technique.

**Design Issues**
- To support real-time PHY-rate decoding with high reliability, FH-CSS has several challenges.
  - Synchronization/Alignment
    - FH-CSS receiver can decode only if the demodulation window aligns with a frequency-hopped chirp.
    - Initial proof-of-concept implementation uses a brute-force linear search.
  - Number of sub-chirps
    - Higher number of sub-chirps provide better robustness to collisions, but it is more susceptible to noise.
  - Frequency hopping pattern
    - It should ensure that FH-CSS has ‘different level of changes’ between adjacent hopping patterns so that they are better distinguishable.

**Evaluation**

**Implementation**
- We implement FH-CSS and standard CSS in GNU Radio using an open source LoRa library, and conduct experiments on USRP B200 SDR.
- To conduct packet collision experiments with precisely controlled collision offsets, we built a LoRa transmitter to mix two modulated signals with deterministic delay in software.

**Preliminary Results**
- SF: 8 / Packet Interval: 100ms / # of Packets: 100 / # of Freq.hop: 16 / Collision Offset Range: [0, 256] (≈ 2^SF, within a chirp)
- Standard CSS has less than 10% decoding rate on average.
- FH-CSS maintains ~90% decoding success rate for almost collision offsets.