Cyclic Code Shift Keying (CCSK) modulation: From a length q BPSK sequence \( P_0(i), i = 0, \ldots, q-1 \), generates a size q dictionary by circularly shift \( P_0(i) \) as \( P_0(i) = P_0(i+k \mod q) \) => Spectral efficiency of \( m/q, m = \log_2(q) \).

Non-Binary code: Generalization of binary code (GF(2)) over a Galois Field \( GF(q=2^m) \), Example: Non-Binary LDPC, Non-Binary Turbo, Non-Binary Polar codes.

CCSK in space: Michibiki (Japan's GPS)
NB-code in space: Beidou 3 (Chinese's GPS).

NB-CODE + CCSK for next generation of IoT?

System model:

![System model diagram](image)

**Advantage:** Every frame is considered as a preamble for detection and synchronization, then as a codeword for the decoder. For example, 240 bits of information:

5G-like

<table>
<thead>
<tr>
<th>Quality</th>
<th>Probole</th>
<th>Data</th>
<th>Redundancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCSP</td>
<td>100%</td>
<td>77%</td>
<td>23%</td>
</tr>
</tbody>
</table>

SNR = -12 dB
FER = 10\(^{-4}\)

Detection: Use a score function (somehow a match filter) adapted to the structure of a QCSP frame [1,2].

Example of score function output with time and frequency offset.

Synchronization: Two on-going patent applications for synchronization in time [3]. Synchronization in frequency is shown to be equivalent to a classical frequency estimation problem enriched by soft-information coming from demodulation and code structure [4].

Non Binary code: Construction of NB Polar, Turbo and LDPC codes. Performance evaluation and simplified hardware decoding algorithm for all codes [5,6,7,8]. Performance for QCSP over GF(64).

\[ R = 1/3, k \approx 120 \text{ bits.} \]
\[ R = 2/3, K \approx 480 \text{ bits.} \]

Example of application: K = 120 bits, CCSK length of GF(64), rate 1/3 NB-LDPC. Transmission OK if and only if:
- Correct detection (Prob: 1 - \( P_d \))
- Exact synchronization (Prob: 1 - \( P_s \))
- Successful correction (Prob: 1 - \( P_p \))

Overall Prob. of error \( \approx P_d + P_s + P_e \)

\[ \approx 10^{-4} \text{ at } -10 \text{ dB of } E_b/N_0 \text{ (simulation result).} \]

Optimally: \( P_d \approx P_s \approx P_e \); On this example, \( P_d < P_s \approx P_e \)

\[ \Rightarrow \text{ Still room for optimization.} \]

Real time demo (450 MHz ASM Band)

Frequency band and chip throughput: 1 MHz, information throughput: 32 kbit/s. Frame Error Rate of \( 10^{-4} \) at -10 dB. Oversampling of a factor 8 at receiver. Half-raised cosine filter.

A new message each second (time + frame id) with Raspberry Pi4 + ETTUS board (B205 mini).
Receiver: ETTUS Board (B205 mini) connected to a PC: detection in C, time and frequency synchronization in Matlab, NB-LDPC decoder in C.

References:


