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Implementation of a Multi-Channel DASH7 IoT Communication System for Packet Investigation and Validation

Dennis Joosens

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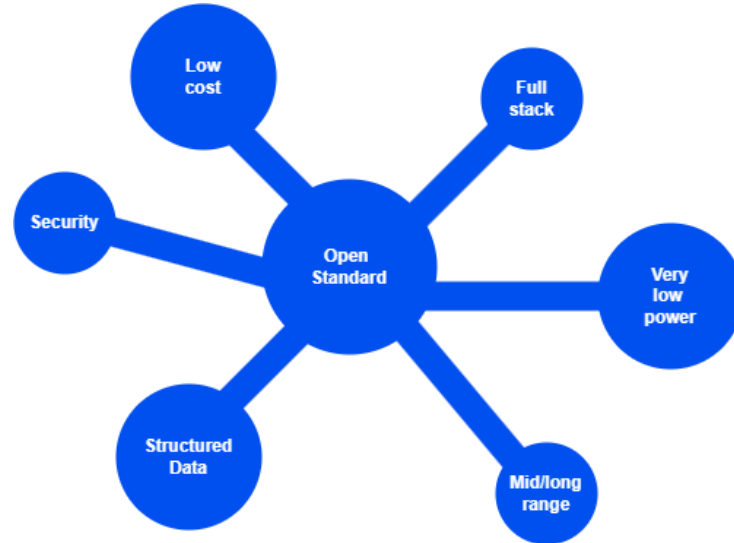
Introduction - LPWAN technologies

Low Power, Long Range and Narrowband Sensor Communication



Use cases DASH7

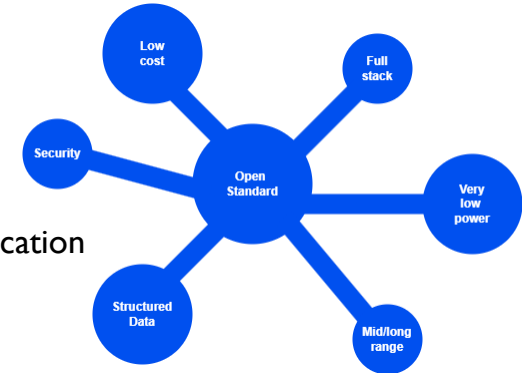
- Localization
- Crowd size estimation
- Energy harvesting
- Smart metering
- Smart cities



DASH7



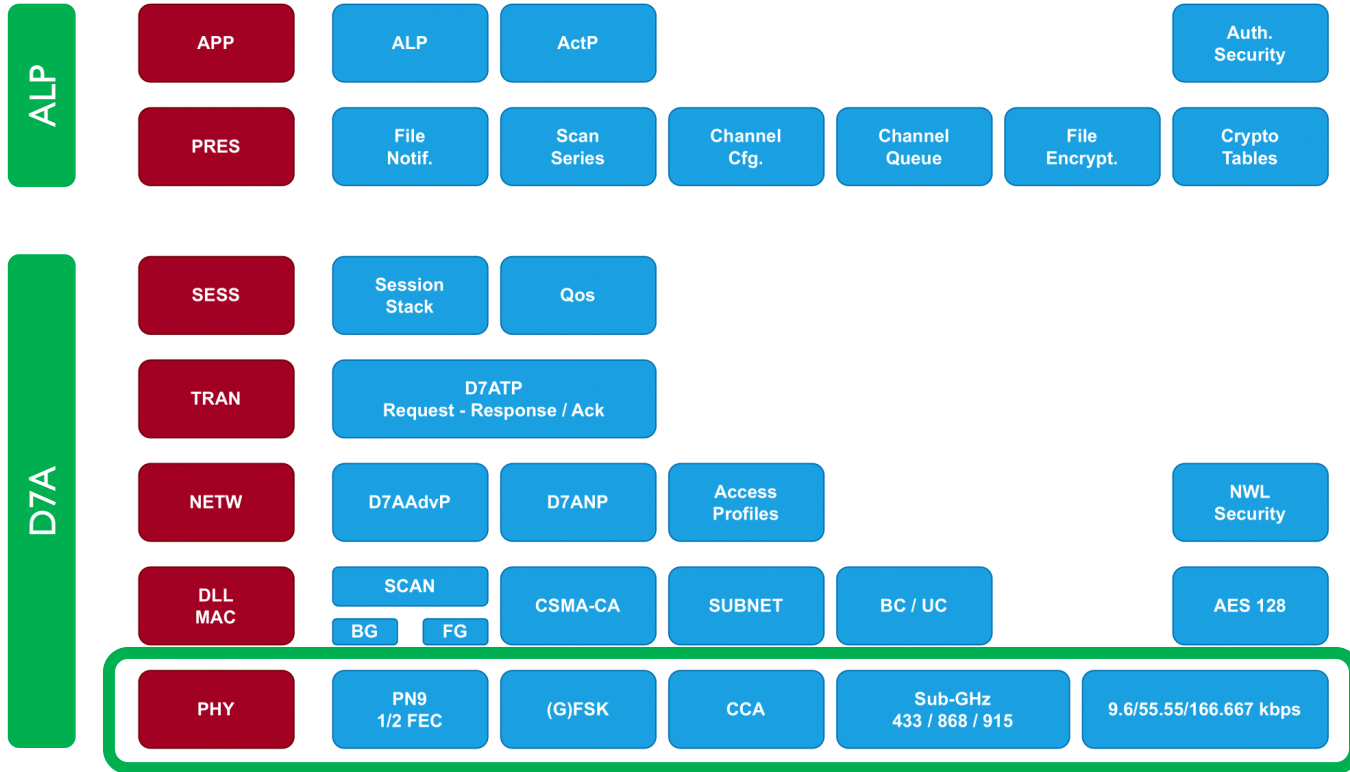
- 2004: ISO ratified
- Originates from ISO/IEC 18000-7 ('DASH7')
 - Describes the parameters for active air interface communication at 433 MHz (2008-2009) of RFID
- Originally created for military use (U.S. military)
- 2009: DOD awarded US \$428 million contract for DASH7 RFID devices, software, and services to four companies: Savi, Northrop Grumman, Systems & Process Engineering Corp., and Unisys => commercial sector
- 2009: announcement of DASH7 Alliance (D7A)
 - Adopted and extended by D7A to support IoT functionalities
- Nowadays:
 - Supports all sub-GHz (ISM/SRD) bands
 - OPEN STANDARD for ultra low power mid-range sensor and actuator communication
 - v1.2 spec published in 2019
- Cases up to 2 - 3 km, practical ranges up to 500 m



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DASH7

Full stack



DASH7 – diving into the PHY

- DASH7 Alliance Protocol (D7AP) is an open-source communication standard for mid-range communications



Binary (G)FSK

Unlicensed Sub-GHz ISM Bands
433 & (868 or 915) MHz

Channel Class	Channel Spacing (c) (kHz)	Symbol Rate (kbps)	Modulation Scheme	Modulation Index	Frequency Deviation (Δf) (kHz)
Lo-Rate	25	9.6	2-(G)FSK	1	± 4.8
Normal	200	55.555	2-(G)FSK	1.8	± 50
Hi-Rate	200	166.667	2-(G)FSK	0.5	± 41.667

DASH7 – diving into the PHY

- * Worldwide coverage with local regulatory limitations
- ** EN 300 220 (Europe) with local regulatory limitations
- *** FCC part 15 in the United States of America.



RF band	Lo-Rate (d)	Normal and Hi-Rate (d)	Start (b)	End
433 MHz*	0, 1, ..., 68	0, 8, 16, ..., 56	433.06 MHz	434.785 MHz
868 MHz**	0, 1, ..., 279	0, 8, 16, ..., 216, 229, 239, 257, 270	863 MHz	870 MHz
915 MHz***	0, 1, ..., 1039	0, 8, 16, ..., 1032	902 MHz	928 MHz



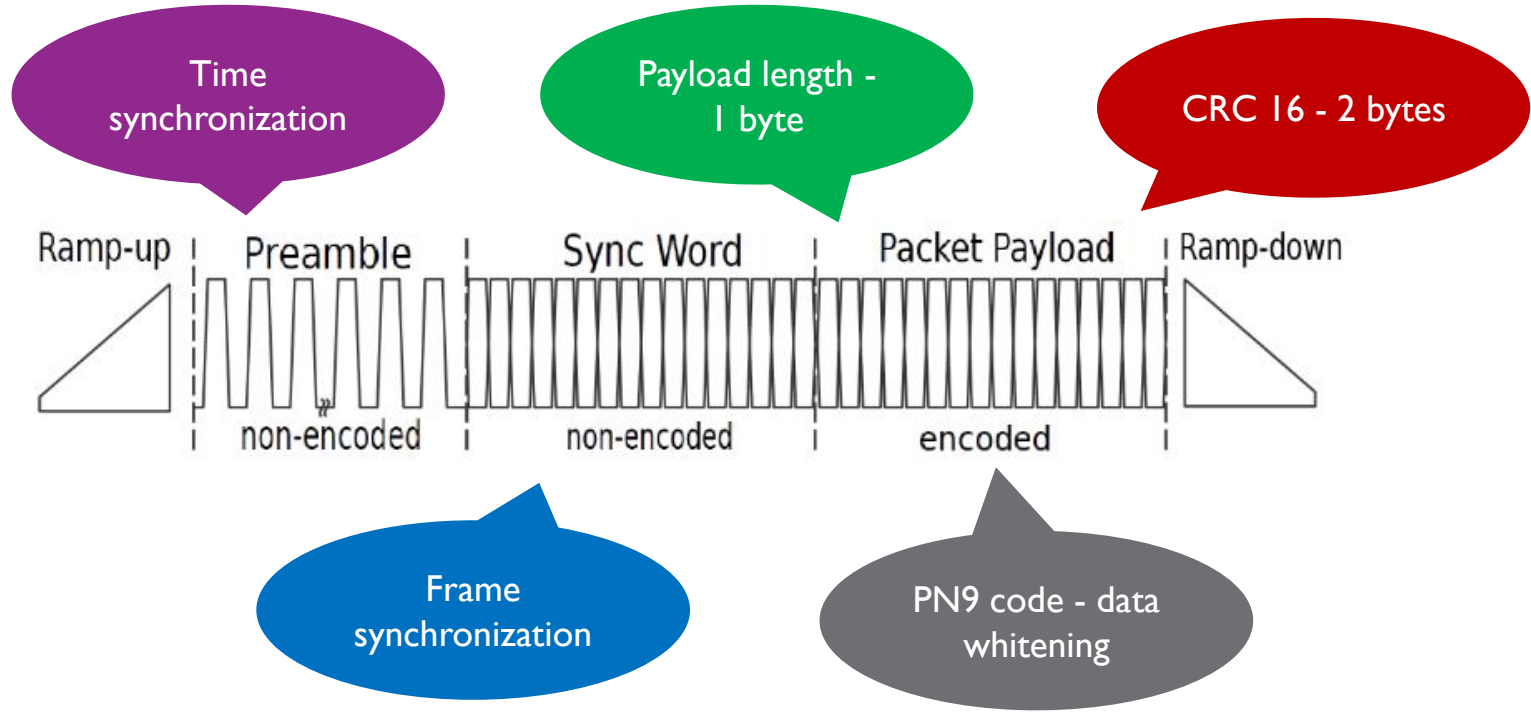
Sync Word Class	Coding Scheme			
	CS0	CS1	CS2	CS3
0	0xF6D0	RFU	0xF498	RFU
1	0x0B67	RFU	0x192F	RFU

PN9

PN9 + 1/2 FEC

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DASH7 – diving into the PHY



DASH7 transmitter

DASH7 transmitter

5 steps

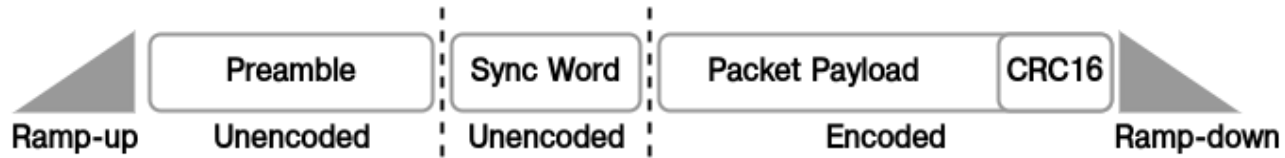
- Packet assembly and data formatting
- Data mapping
- Symbols-to-waveform conversion
- Baseband modulation

- SDR modulation

1, 2. - Packet assembly and data formatting + data mapping

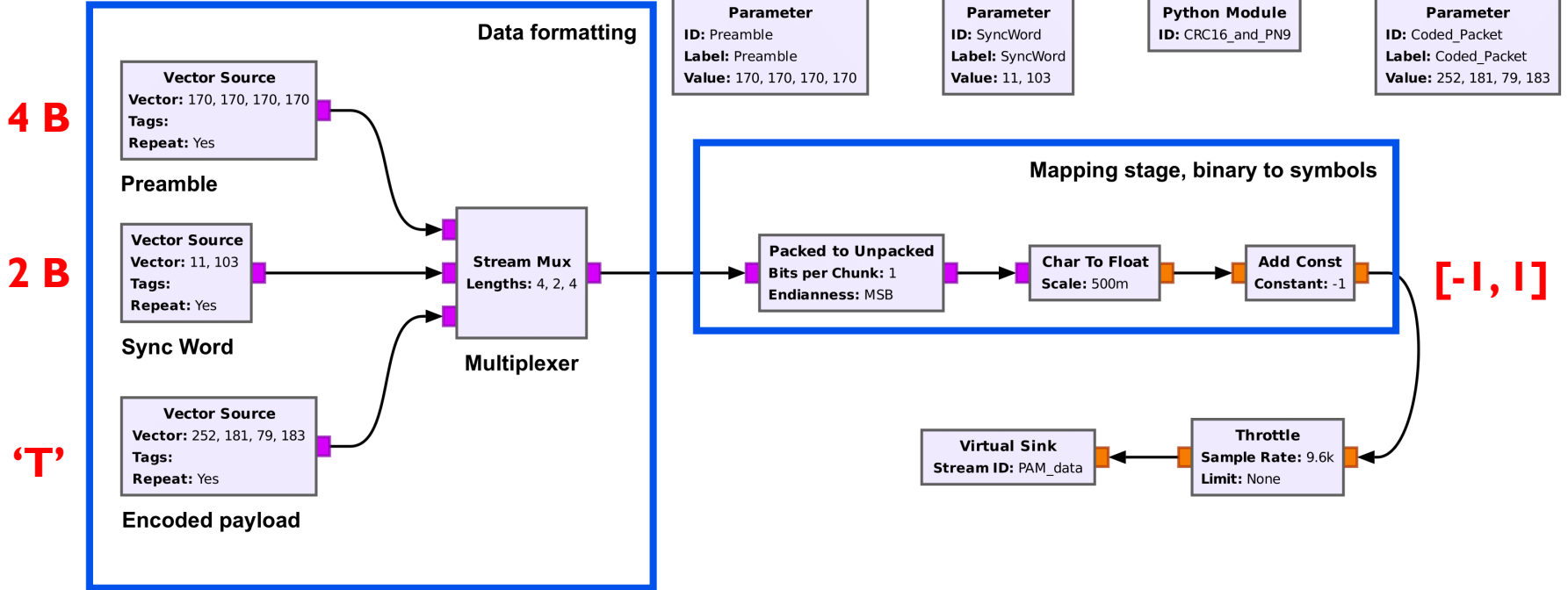
DASH7 transmitter

1, 2 Packet assembly and data formatting + data mapping



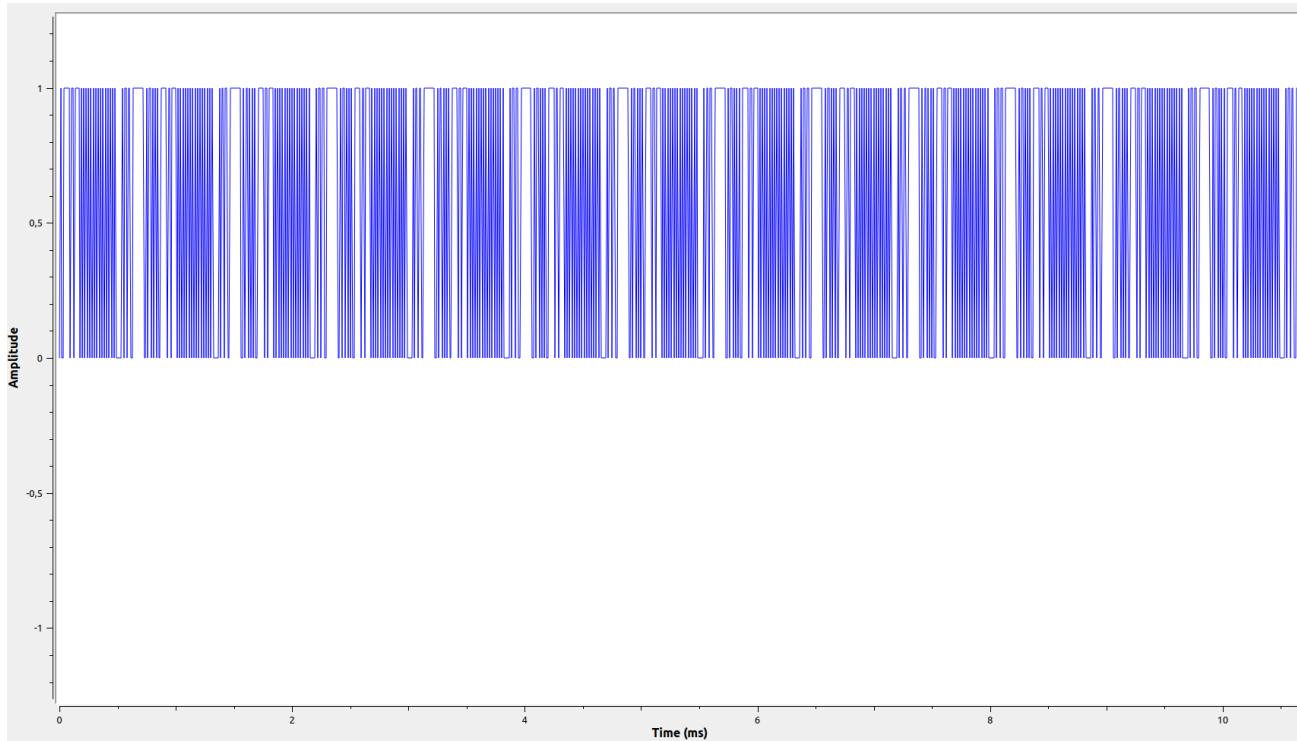
DASH7 transmitter

1, 2 Packet assembly and data formatting + data mapping



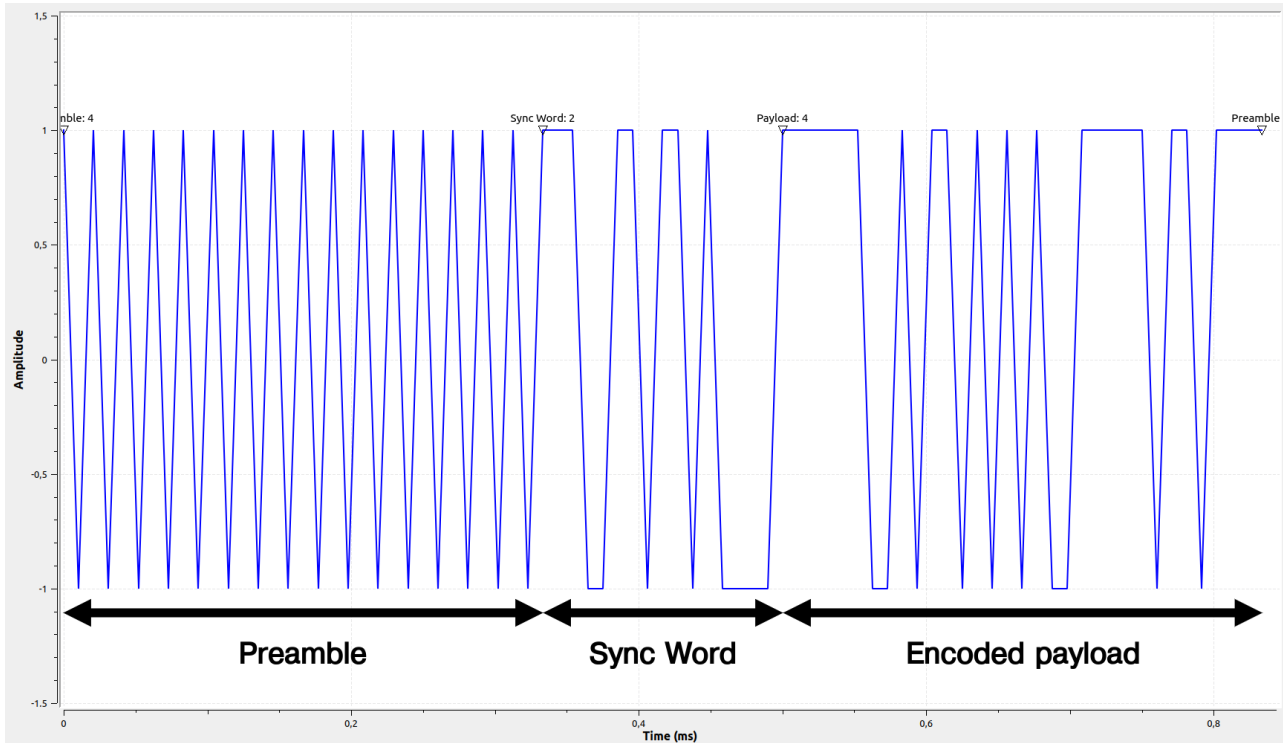
DASH7 transmitter

1, 2 Packet assembly and data formatting - output T.D.



DASH7 transmitter

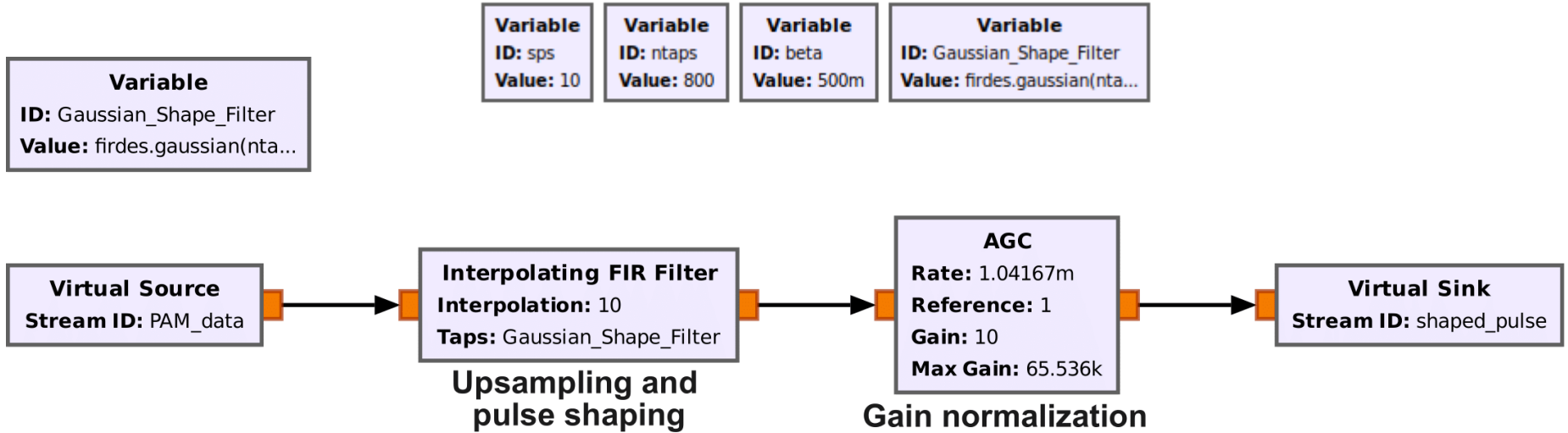
1, 2 Data mapping - output T.D.



3.TX - symbols-to-waveform conversion

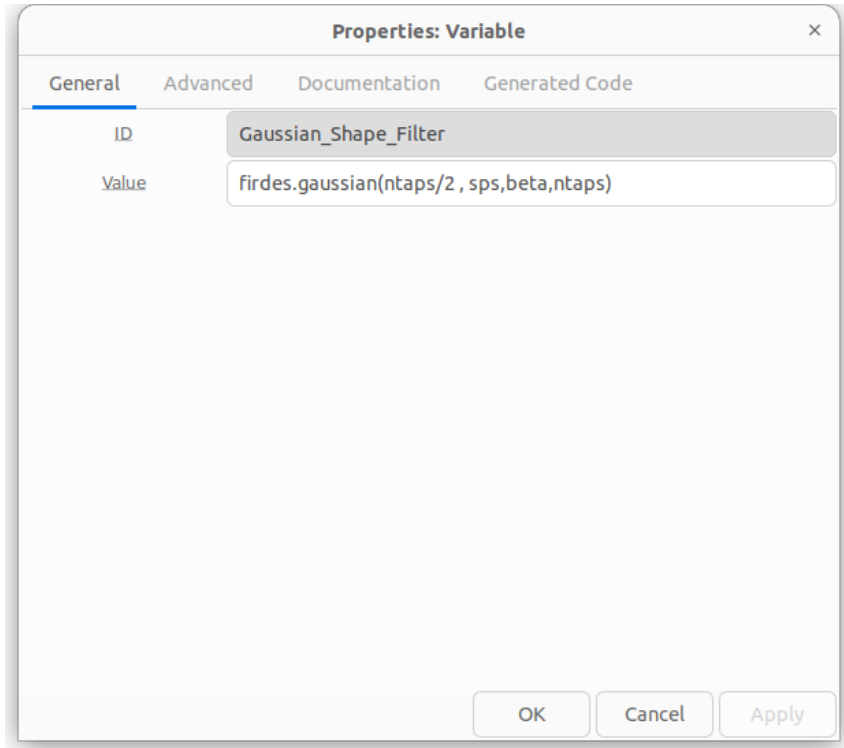
DASH7 transmitter

3. Symbols-to-waveform conversion



DASH7 transmitter

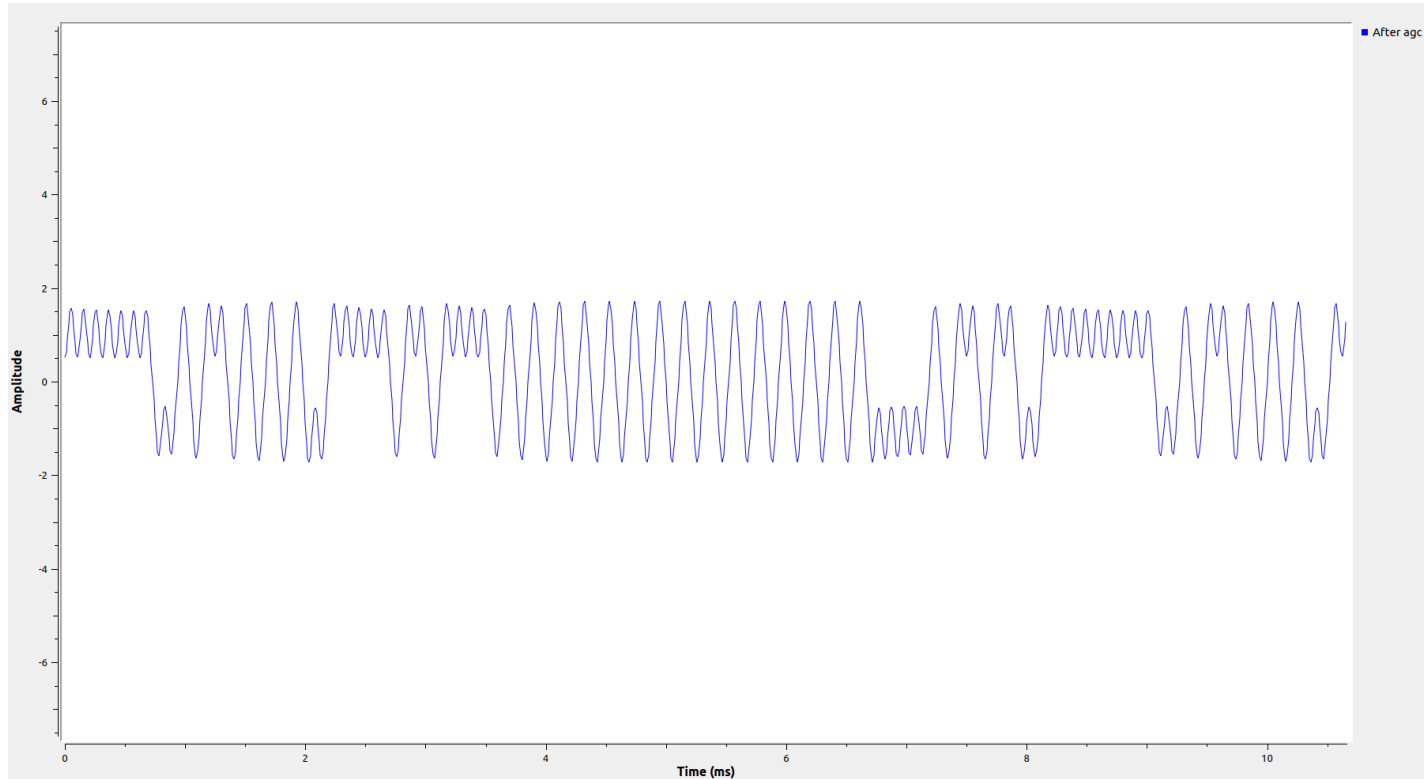
3. Symbols-to-waveform conversion



Variable ID: sps Value: 10	Variable ID: ntaps Value: 800	Variable ID: beta Value: 500m	Variable ID: Gaussian_Shape_Filter Value: firdes.gaussian(nta...
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DASH7 transmitter

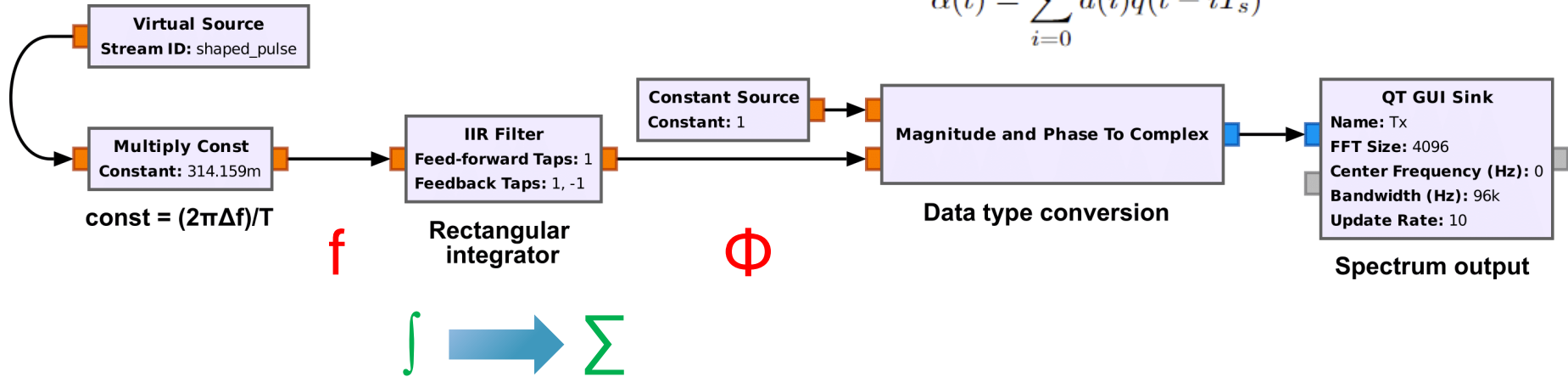
3. Symbols-to-waveform conversion - output T.D.



4.TX - Baseband modulation

DASH7 transmitter

4. Baseband modulation



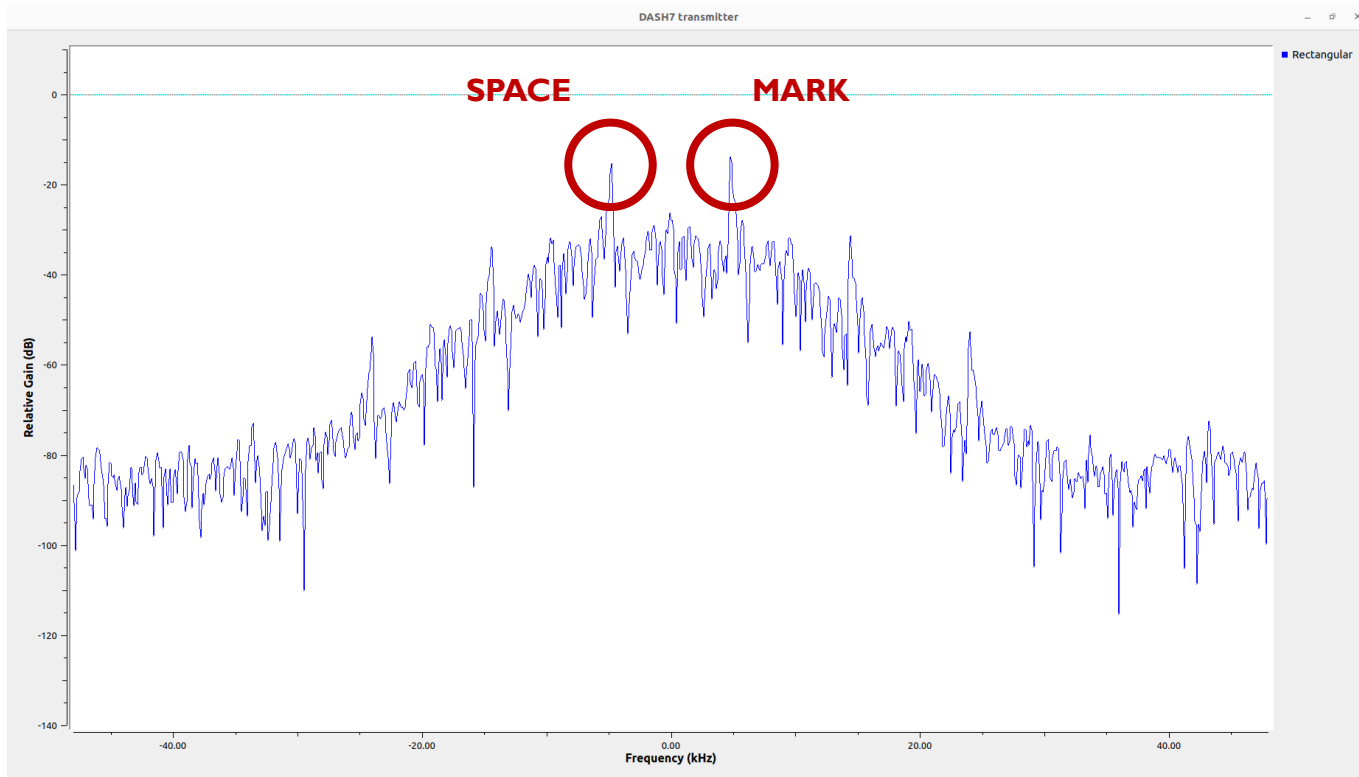
$$s(t) = Ae^{j\Phi(t)}$$

$$\Phi(t) = 2\pi h \int_0^t \alpha(\tau) d\tau$$

$$\alpha(t) = \sum_{i=0}^L a(i)q(t - iT_s)$$

DASH7 transmitter

4. Baseband modulation - output F.D.



DASH7 transmitter

5. SDR modulation

- Baseband signal onto a carrier (passband)
- $F_c = 863.0125$ MHz (CH0)
- $BW = 7.68$ MHz
- Norm. gain = 0.8

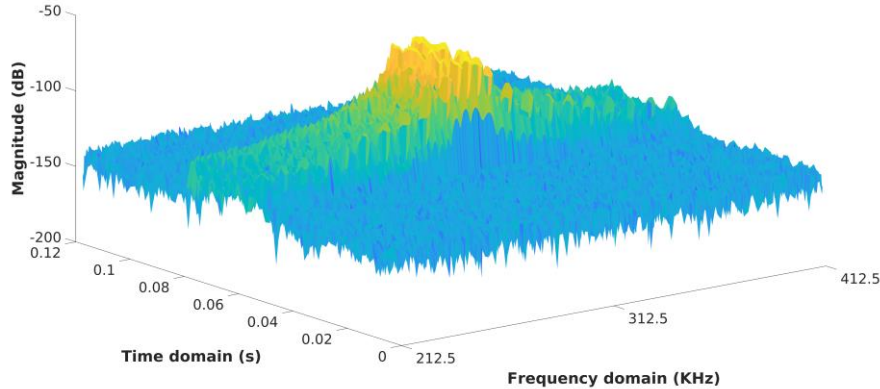


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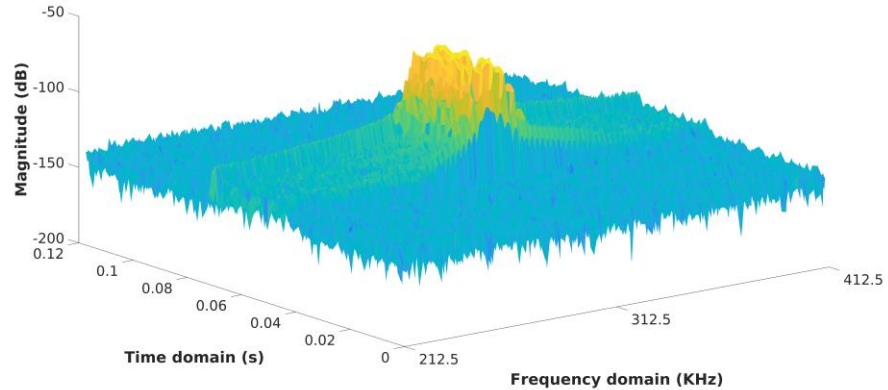
Looking at the spectrum

DASH7 transmitter

Signal in T.F. domain



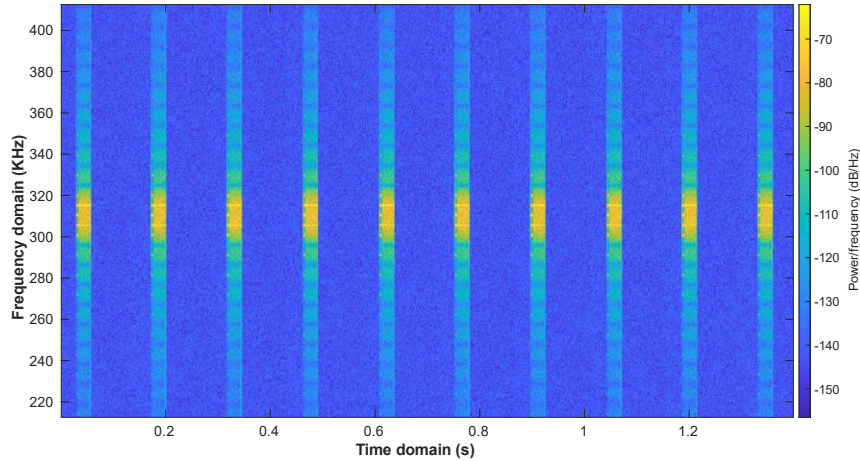
FSK



Gaussian FSK, BT = 0.5

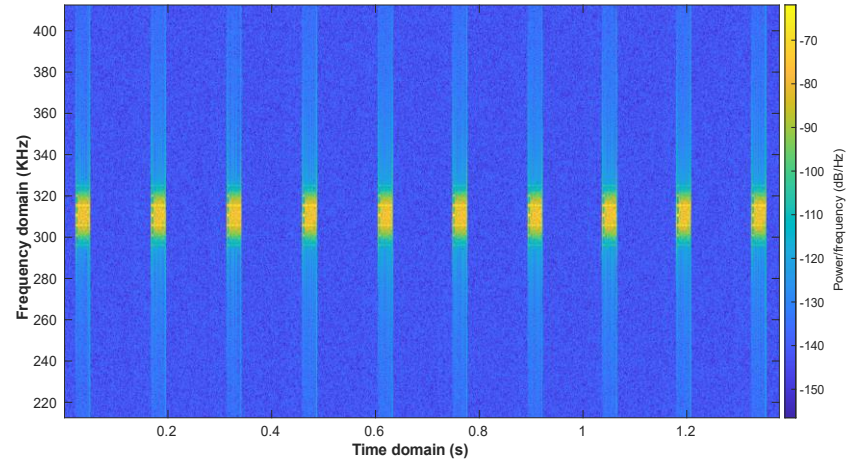
DASH7 transmitter

Signal in T.F. domain



FSK

Gaussian FSK, BT = 0.5



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DASH7 receiver

DASH7 receiver

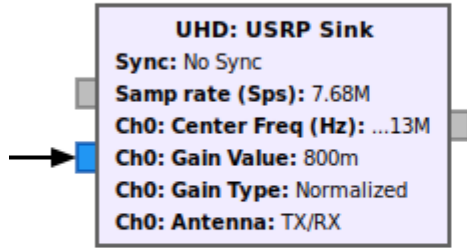
6 steps

- SDR reception
- Frequency downconversion
- Demodulation
- Time synchronization
- Frame synchronization
- Payload decoding

I. SDR reception

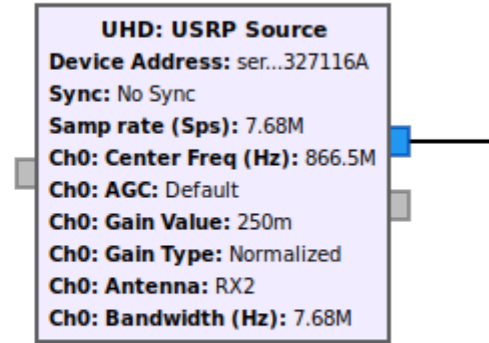
DASH7 receiver

SDR reception



TX connection to USRP B210

wireless
channel



RX connection to USRP B210

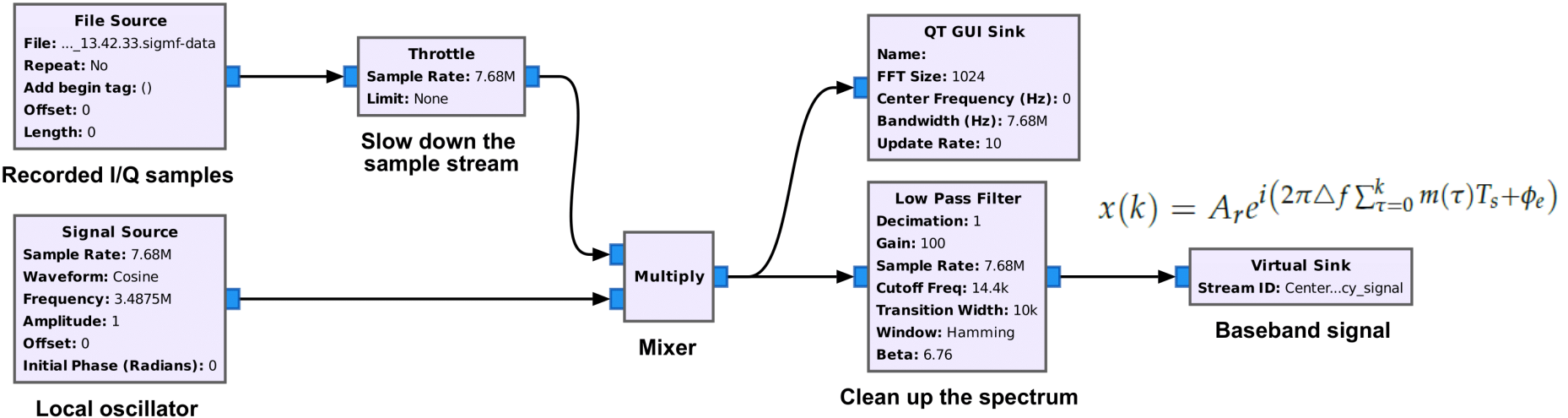
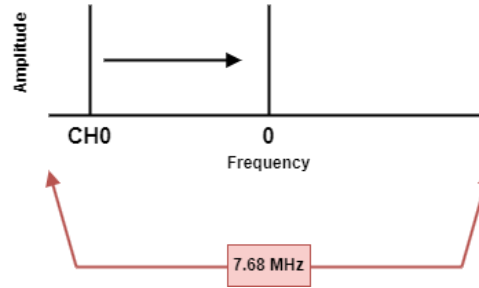
$$g(t) = Ae^{i2\pi(f_c t + \Delta f \int_0^t m(\tau) d\tau)}$$

2. Frequency downconversion

DASH7 receiver

2. Frequency downconversion

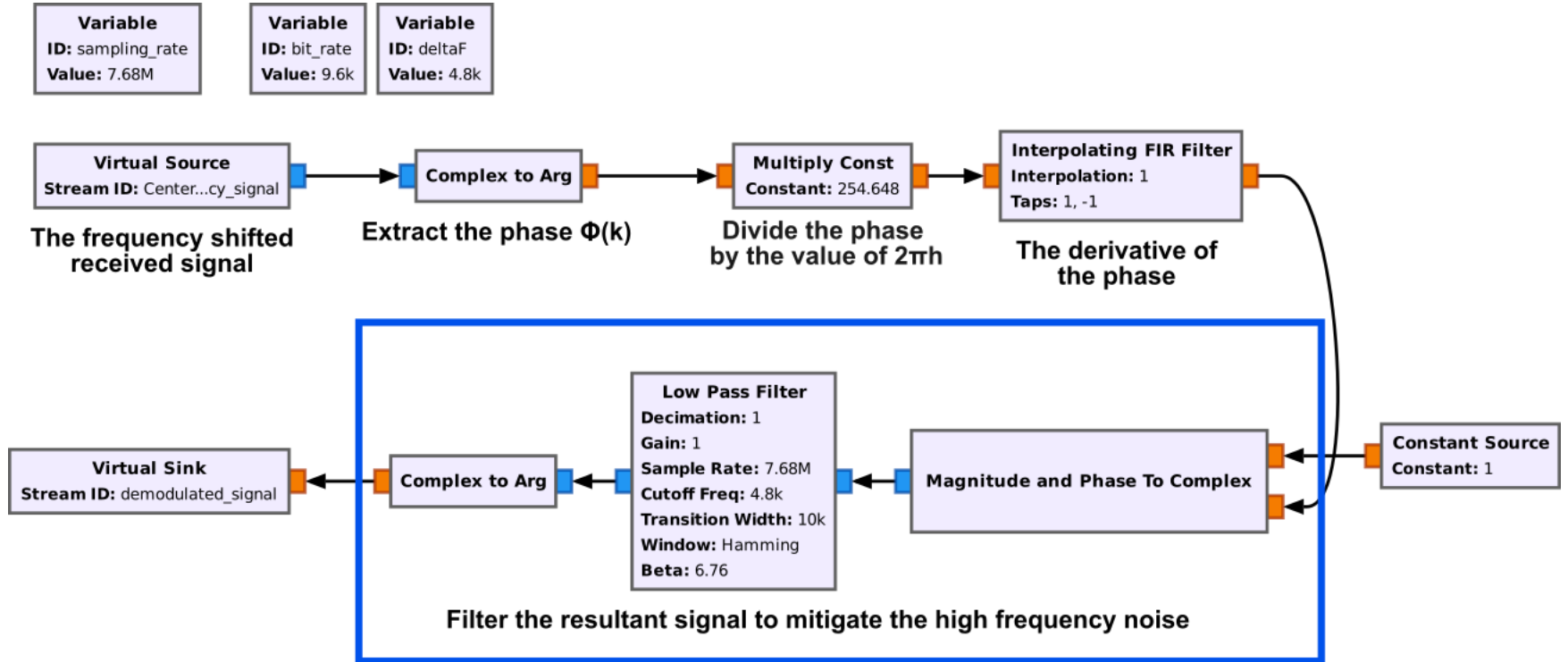
Variable ID: sampling_rate Value: 7.68M	Variable ID: IF Value: 3.4875M	Variable ID: ch Value: 0
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3. Demodulation

DASH7 receiver

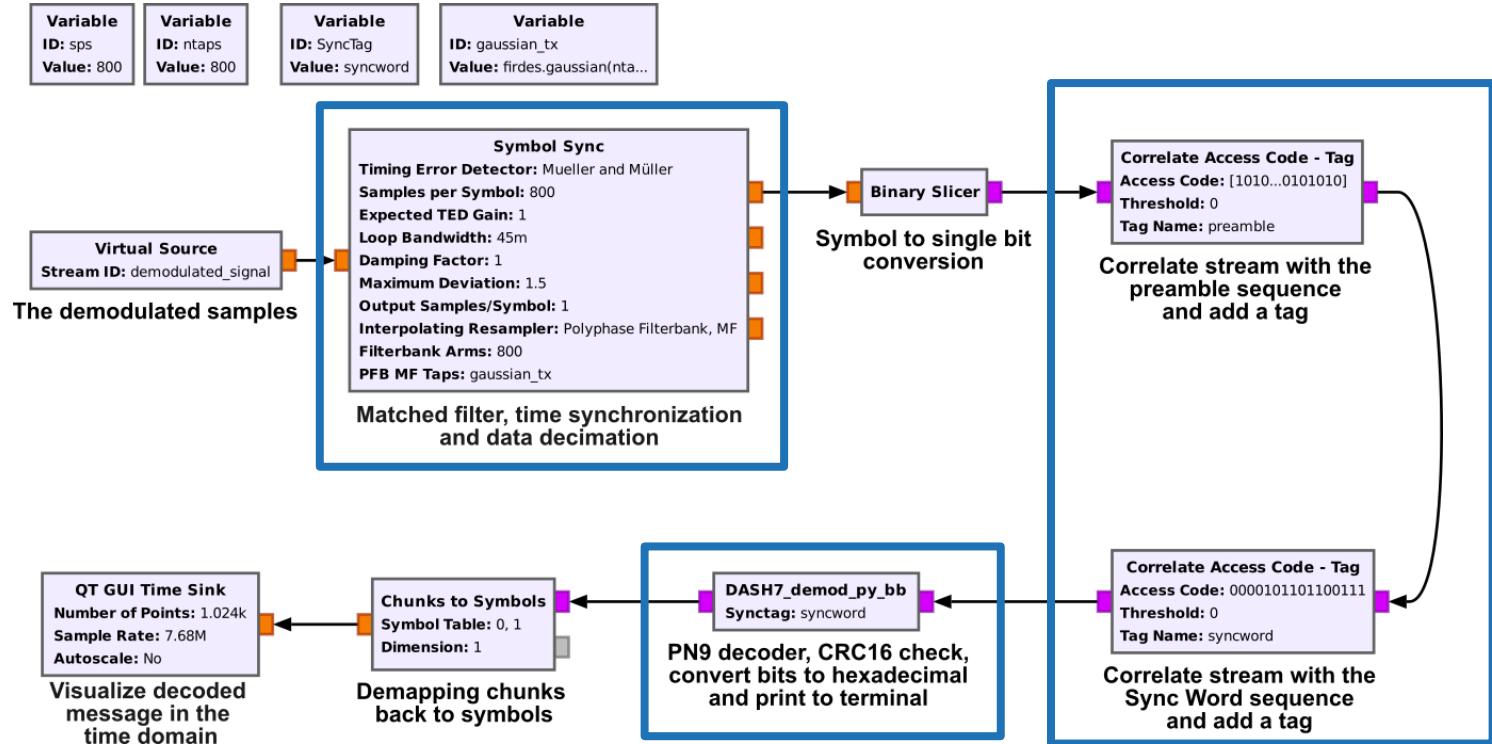
3. Demodulation



4, 5, 6. Time + Frame synchronization + Payload decoding

DASH7 receiver

4, 5, 6 Time + Frame synchronization + Payload decoding



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DASH7 receiver

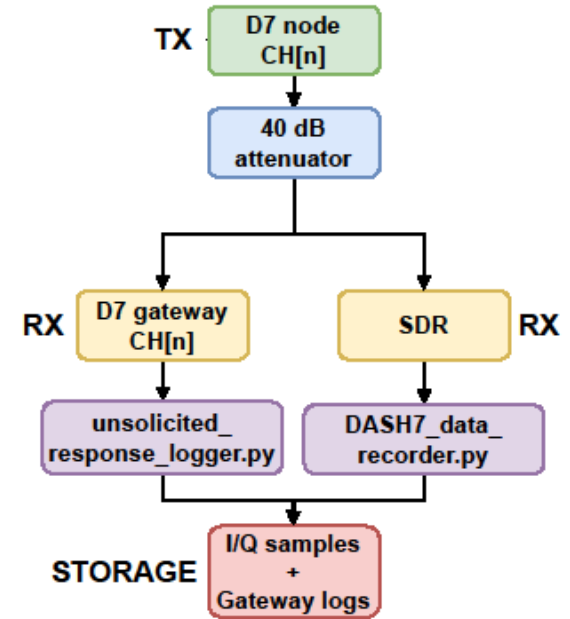
Time + Frame synchronization + Payload decoding - output T.D.

1000001011101100111....

Experimental results

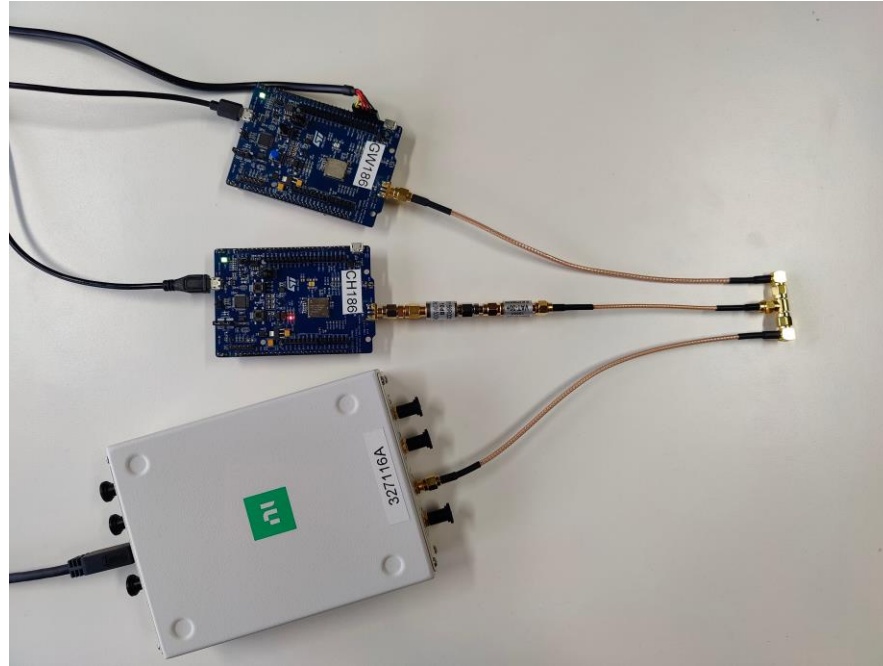
Experimental results

- ST B-L072Z-LRWAN1 dev board
- TX: D7 node using [Sub-IoT stack](#)
- RX: D7 GW using [Sub-IoT stack](#)
- RX: USRP B210 Channel 186, Lo-Rate, 868 MHz
- 40 dB attenuator + RF splitter
- Payload: [0x00, 0xAB, 0XCD]
- 7.68 MS/s
- Normalized gain: 0.25
- Saved as CI_LEI6



Experimental results

Bench setup



Experimental results

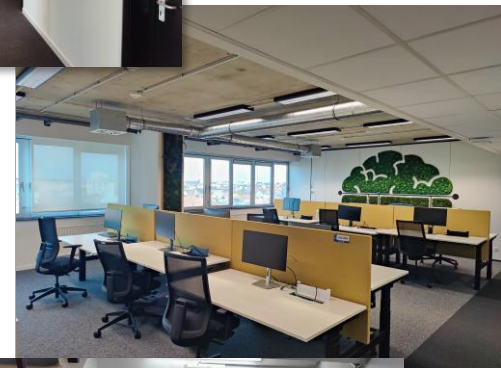
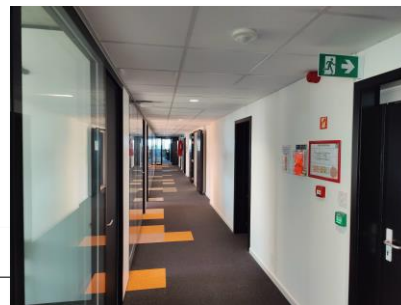
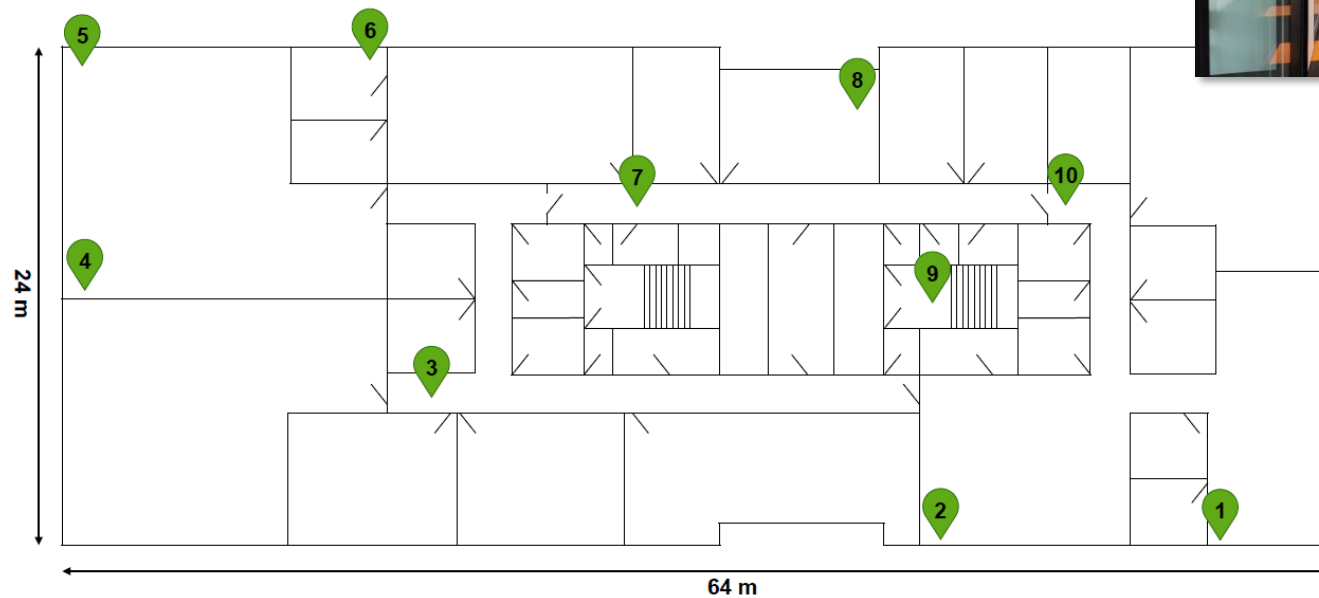
Output GRC with real data

- 3 channels, 30 packets sent, all recovered
- Investigate time domain, console logs, parse hexstring

```
Found packet 1 syncword at location 10200
2024-08-06 14:43:46.931153
MsgLength = 25 bytes
Msg = 24 1 110 32 33 49 55 52 52 0 45 0 23 128 110 0
32 64 0 3 0 171 205 199 20
Hex:
18 01 6e 20 21 31 37 34 34 00 2d 00 17 80 6e 00
20 40 00 03 00 ab cd c7 14
CRC read = 1 1 0 0 0 1 1 1 0 0 0 1 0 1 0 0
CRC calc = 1 1 0 0 0 1 1 1 0 0 0 1 0 1 0 0
Check is True
correlate_access_code_tag_bb :debug:
writing tag at sample 11577
```

Experimental results

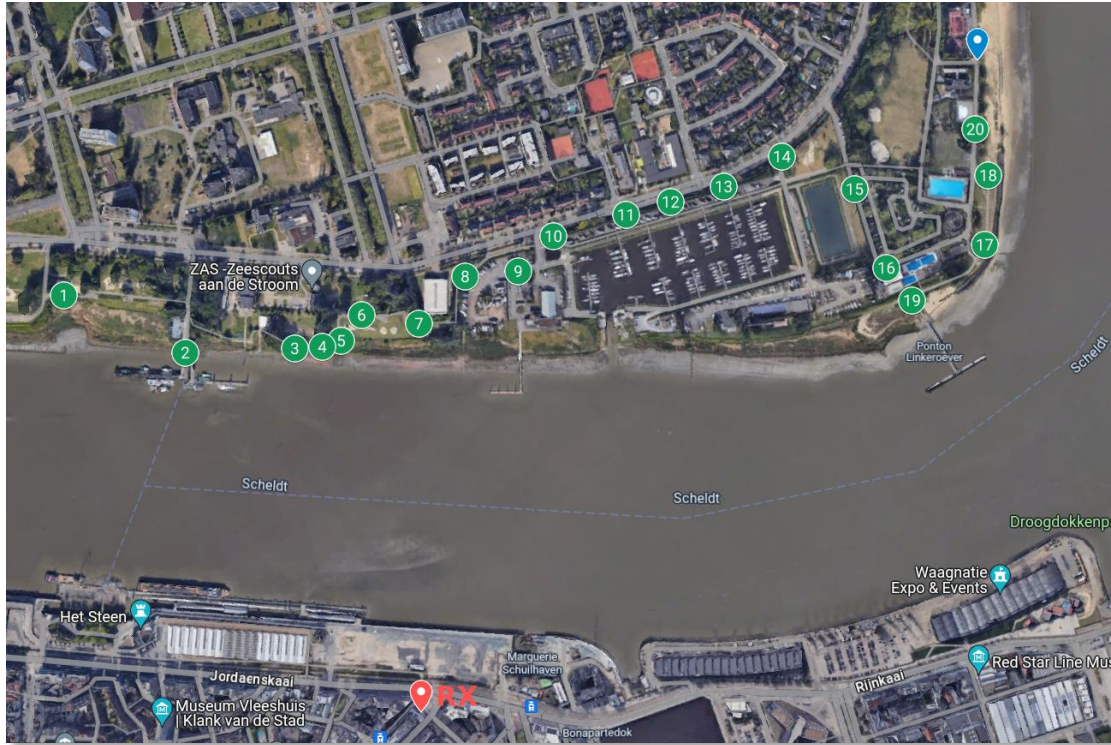
Continued...



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Experimental results

Continued...



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Conclusion & future work

Conclusion & future work

- DASH7 PHY investigation and testing tool for simulation and real-world experiments
- Understand how DASH7 PHY works
- Data set of DASH7 messages

- Make it more dynamic
 - CFO correction system
- Implementation of other layers
- Implementation of Normal Rate and Hi-Rate channel classes
- Implementation of $\frac{1}{2}$ FEC

Resources

- GRC flowgraphs

- <https://gitlab.ilabt.imec.be/dash7/multi-channel-dash7-iot-communication-system>



- Data set

- <https://doi.org/10.5281/zenodo.13734533>
- Signal Metadata Format (SigMF)

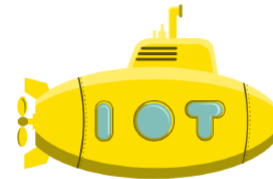


<https://www.youtube.com/@dash7academy581>

<https://www.dash7-alliance.org/>

<https://www.dash7-alliance.org/download-specification/>

<https://github.com/Sub-LoT/Sub-LoT-Stack>



Contact

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- idlab.uantwerpen.be



Thank you for your attention!



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