On the Implementation of the NATO Narrow Band Waveform with Low-Cost Software Defined Radio Platforms

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Outline

- Motivation
- Introduction
- Review of the Narrow Band Waveform (NBWF) Physical Layer (STANAG 5631)
- Review of the NBWF Link Layer (STANAG 5632)
- Basic NBWF Physical Layer Implementation
- Advanced NBWF Physical Layer Implementation for low-cost SDR platforms
- NBWF Link Layer Implementation
- Real-time Qt Application for NBWF
- Conclusion and Future Work

Motivation

- Work in the scope of a Belgian MoD Research Study SIC-10 on Cognitive Radio Networks (Implementation of several waveforms in C++ with low-cost SDR platforms)
- The principal objective of this presentation is to demonstrate the real-time implementation of the NBWF with low-cost SDR platforms, such as the Universal Software Radio Peripheral (USRP).
- More specifically, the physical layer and some parts of the data link layer of the NBWF are implemented in software.
- This presentation gives an idea of the effort required to port the NBWF from a basic implementation intended for simulations to a more advanced implementation with low-cost SDR platforms.
- As the STANAGs of the NBWF are being ratified, this presentation provides insights for implementing the NBWF on more sophisticated military SDR platforms.
- Proposition of using the NBWF as a basic waveform for the VHF link in the upcoming EDA Cat B project called MAENA
- Idea of using this work for a NATO reference implementation

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Introduction

- There is currently no narrowband Combat Net Radio (CNR) STANAG waveform for international and combined missions providing interoperability in Network Centric Operations (NCO)
- The principal objective of the Narrow Band Waveform (NBWF) is to achieve coalition interoperability within lower tactical levels
- Military Software Defined Radio (SDR) equipment provides the flexibility to incorporate new waveforms and functionalities without having to upgrade or to replace hardware components.
- Therefore, the SDR technology provides an efficient and inexpensive way to implement the NBWF

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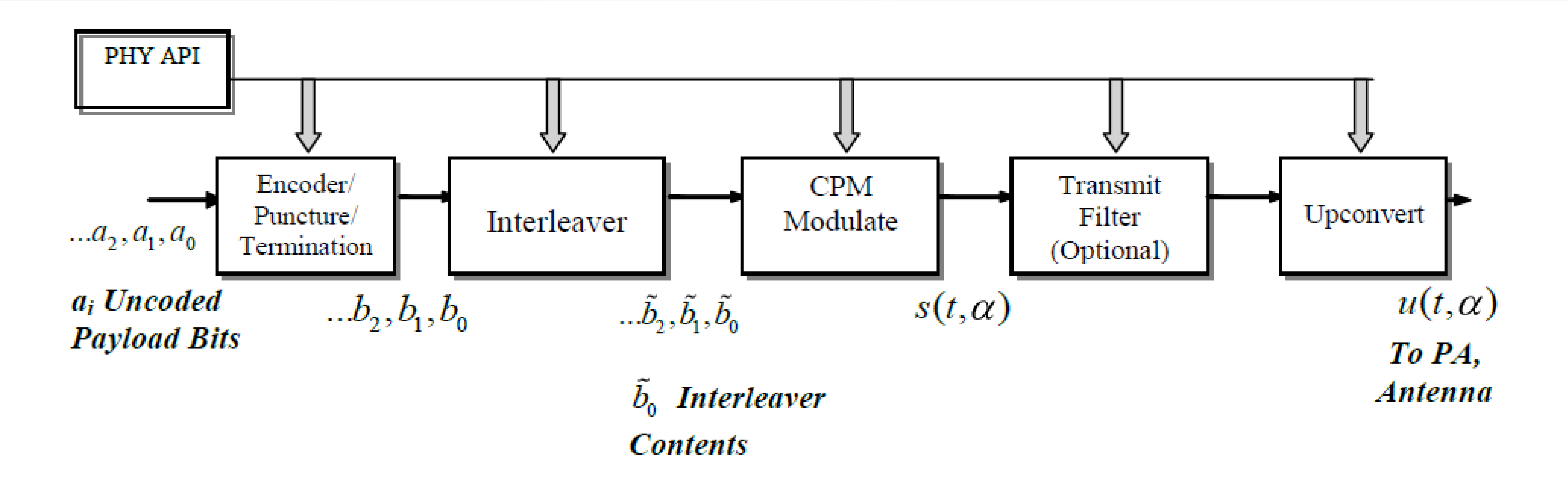
Review of the NBWF Physical Layer (STANAG 5631)

- The uncoded payload bits are encoded and punctured, interleaved, modulated by the CPM, filtered and upconverted.



Review of the NBWF Physical Layer (STANAG 5631)

- The NBWF uses bandwidths of 25 KHz up to 50 kHz with on-air bit rates up to 82 kbps in the VHF or lower UHF bands with continuous phase modulation (CPM)

Waveform Modes	User Data Rates (kbps)	L	Mc	h	Pulse Shape	Code Rate	Symbol Rate(ksps)	Nominal 99% BW (kHz)
N1	20	2	2	1/2	REC	2/3	30	25
N2	31.5	2	2	1/4	REC	3/4	42	25
N3	64	3	2	1/6	REC	4/5	80	25
N4	82	3	2	1/9	REC	6/7	96	25
N5	40	2	2	1/2	REC	2/3	60	50
N6	63	2	2	1/4	REC	3/4	84	50
NR	10	2	2	1/2	REC	1/3	30	25

- L is the number of symbol intervals
- Mc is the alphabet size
- h is the modulation index

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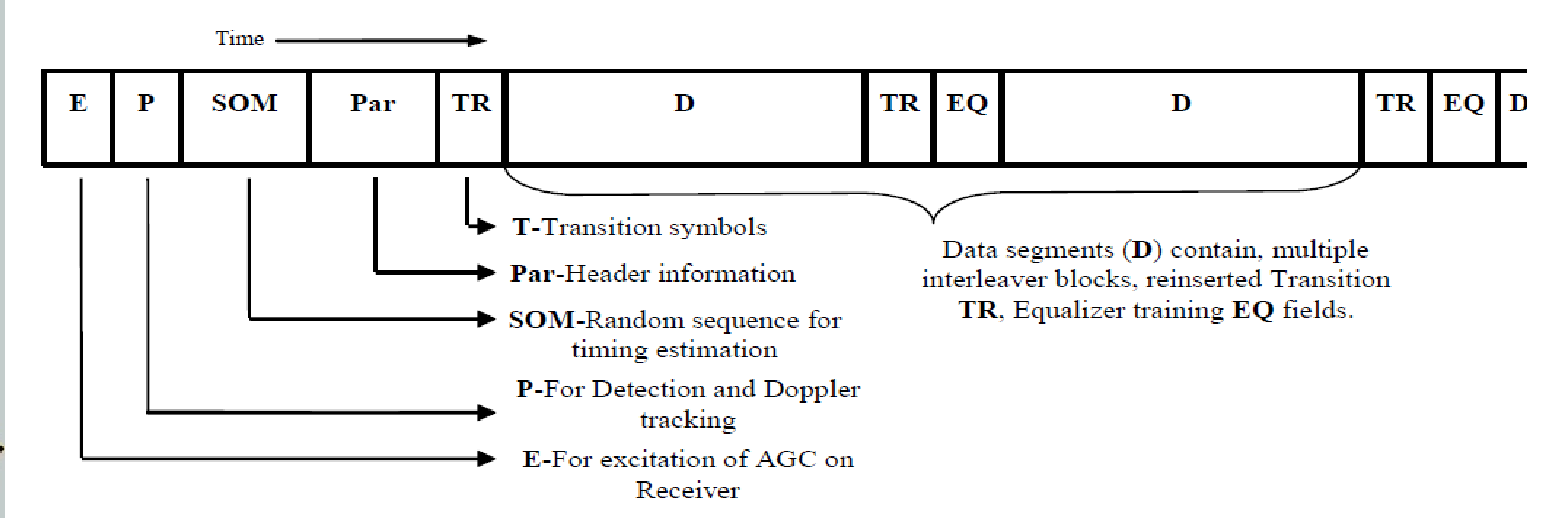
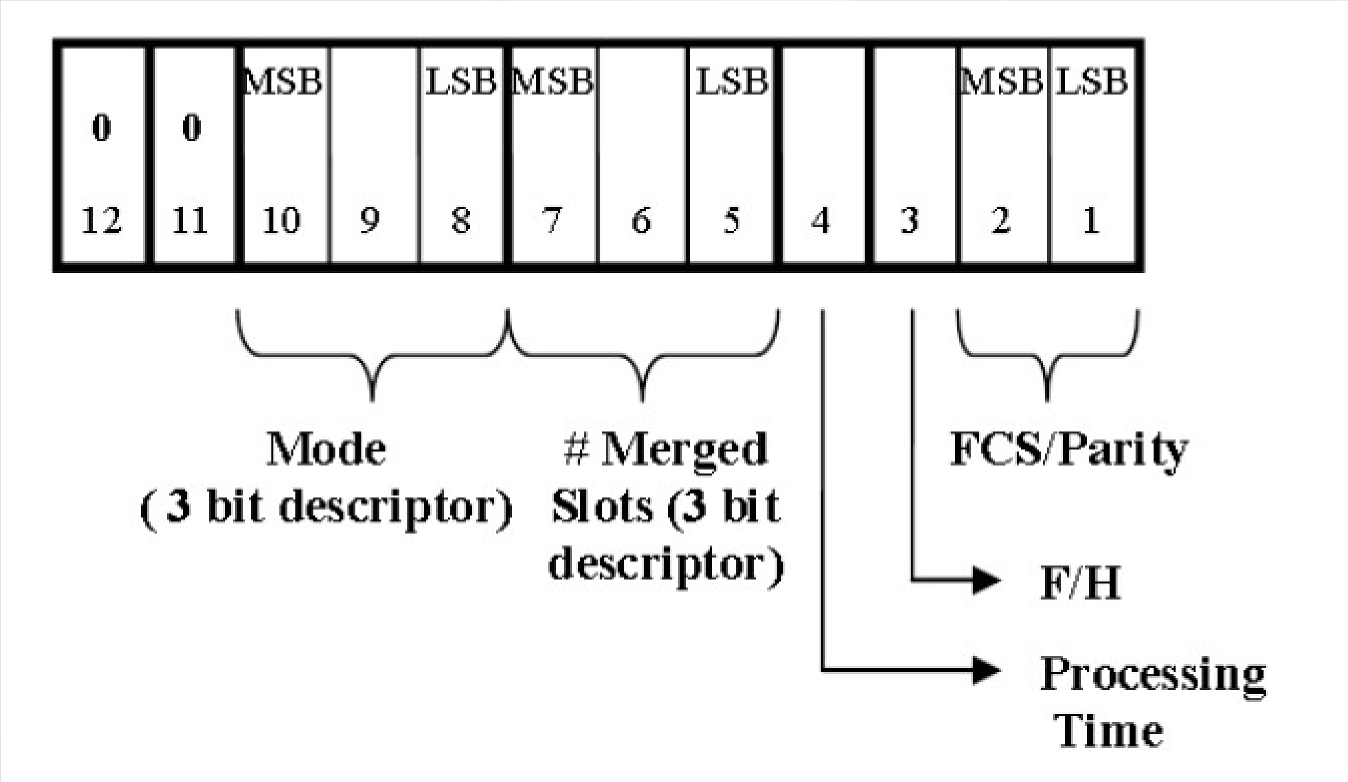
Review of the NBWF Physical Layer (STANAG 5631)

- The slot size of the NBWF is 22.5 ms (to be in accordance with MELP frame length). There can be single slots or merged slots with or without processing time applied to the final slot. P=45 symbols, SOM= 63 symbols, Par=48 symbols, TR=2 symbols, EQ=16 symbols



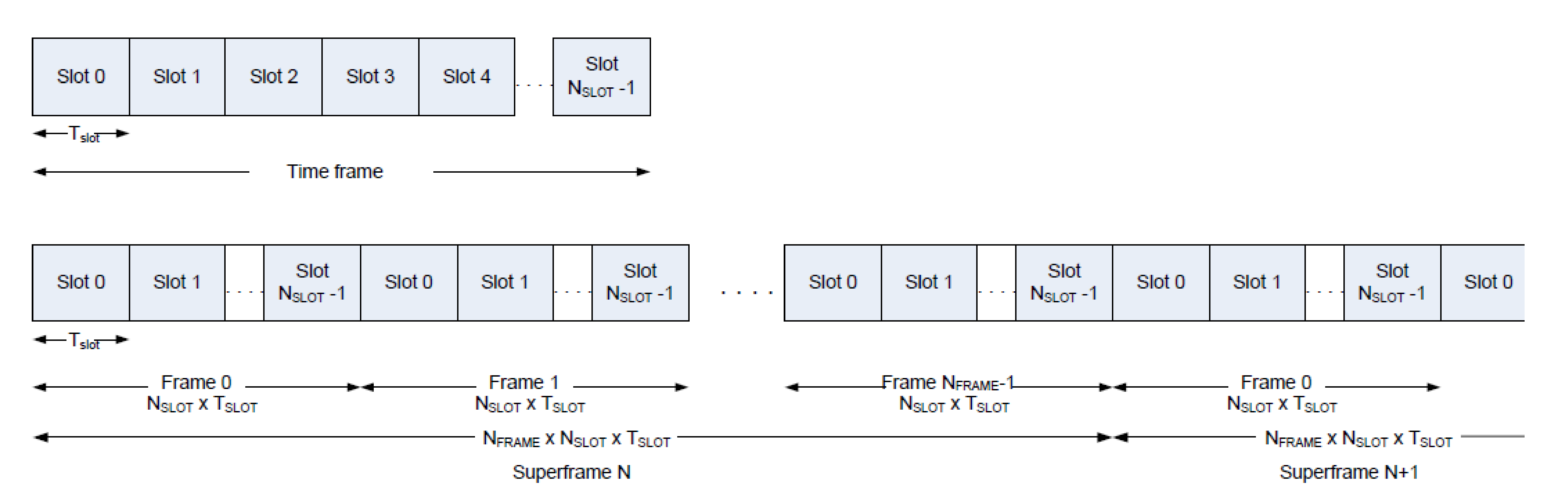
Review of the NBWF Physical Layer (STANAG 5631)

- The contents of the “Par” register contains 12 information bits. These 12 bits are block coded using the extended Golay (24,12) code.



Review of the NBWF Link Layer (STANAG 5632)

- The slots are organized into frames, superframes and hyperframes as shown in the figure.



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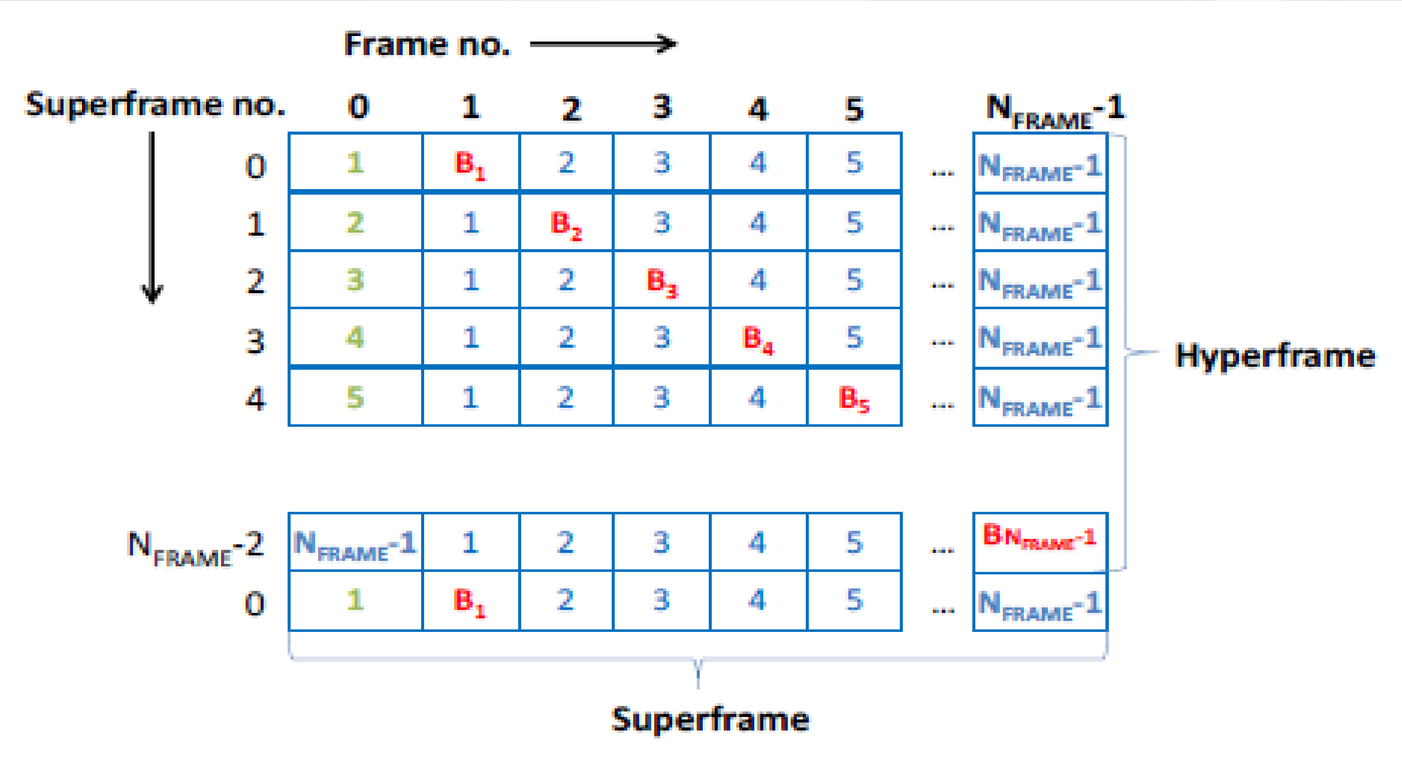
Review of the NBWF Link Layer (STANAG 5632)

- Beacons are used for time synchronization and network housekeeping.



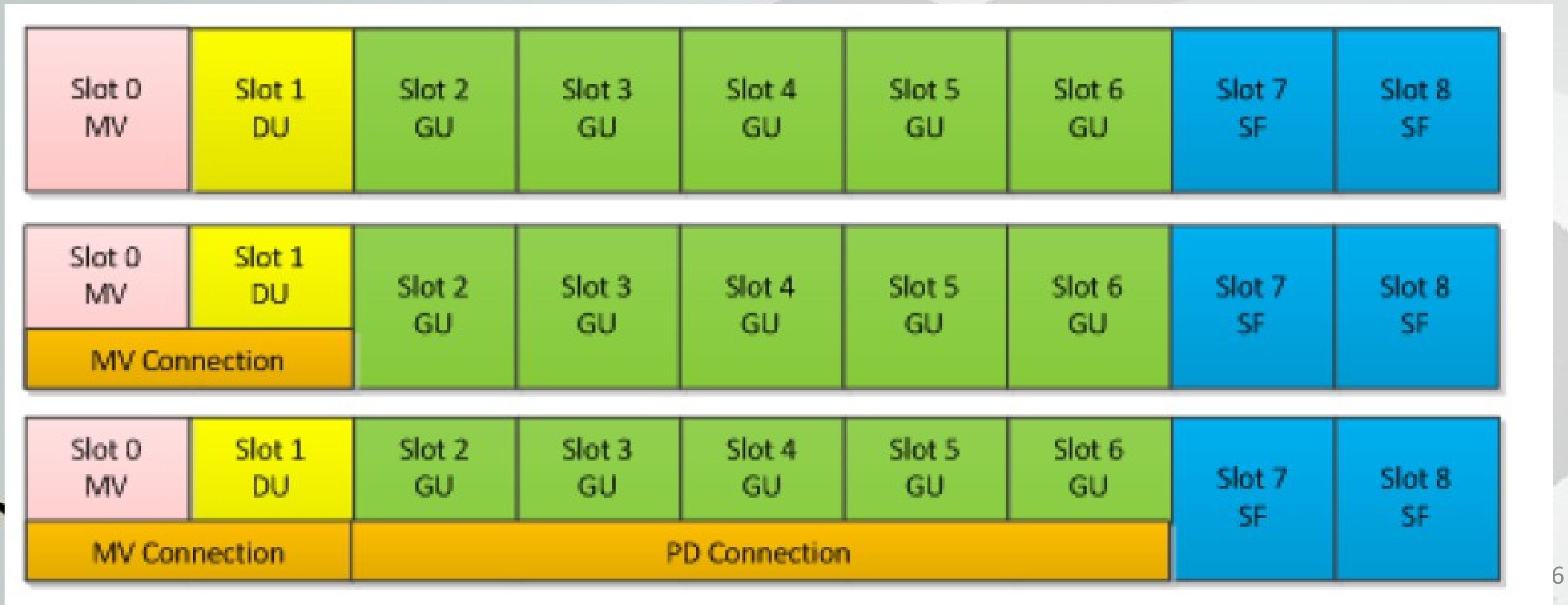
Review of the NBWF Link Layer (STANAG 5632)

- There are 4 different types of time slots.

SLOTTYPE	Short Description
MV	Multicast voice slot
SF	Superframe slot
DU	Dual use slot
GU	General use slot
RESERVED	Reserved slots of type DU and GU
FREE	Unreserved slot of type DU and GU

Review of the NBWF Link Layer (STANAG 5632)

- The NBWF has a Time Division Multiple Access (TDMA) structure of 9 slots. Slots can be reserved for Multicast Voice (MV), Packet Data (PD), Unrestriced Service (US) and Selective Call (SC) Connections.

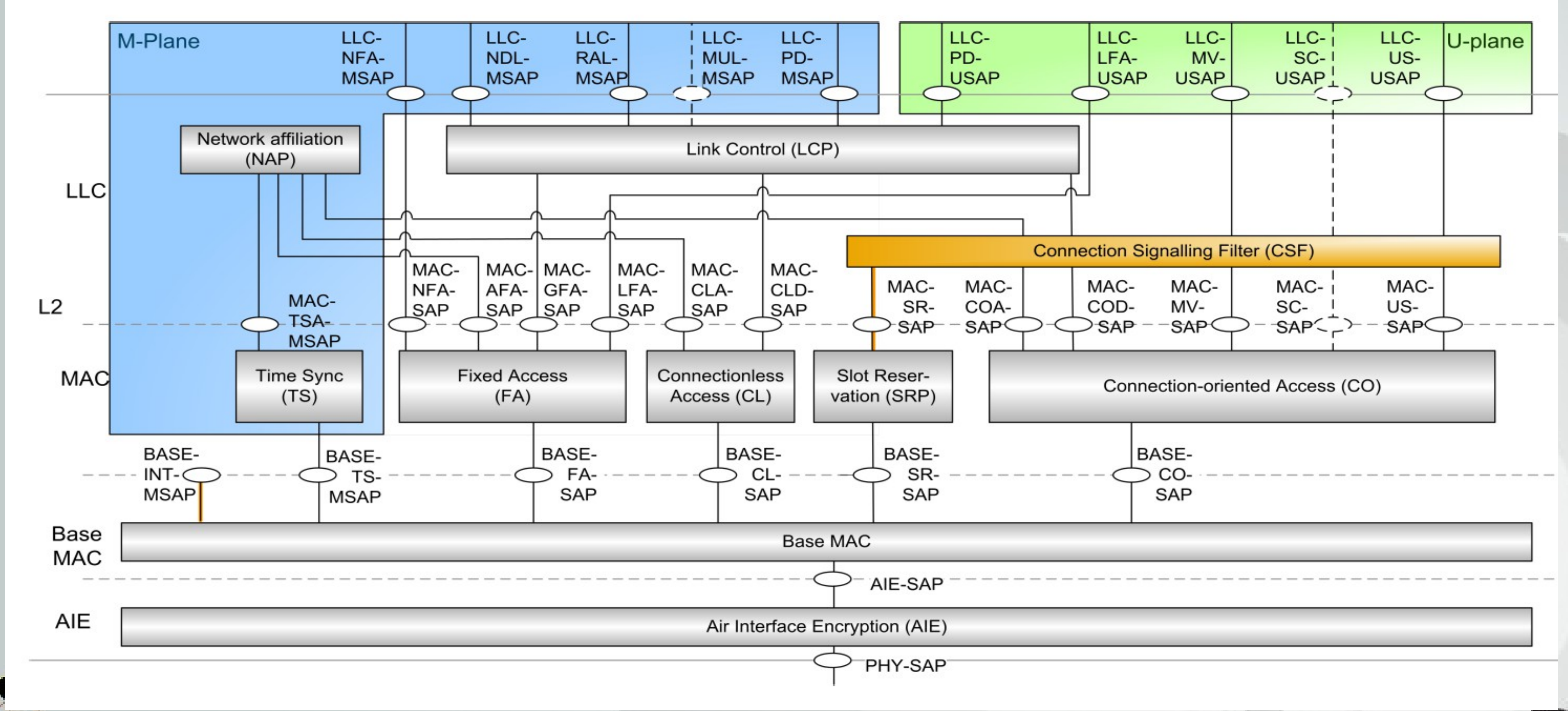


Review of the NBWF Link Layer (STANAG 5632)

- This figure illustrates when the TDMA structure is configured for no relays. A Connection Request (CR) can request a maximum of 4 Connection Confirm (CC), which are all transmitted in the two first slots in time. At the end, Disconnect Request (DR) can request 4 Disconnect Confirm (DC).

Slot no. ->	0	1	2				
Slot type ->	MV	DU	GU		GU	SF	SF
Time frame 1	CR	Pre-empt		. . .			
Time frame 2	CC x 2	CC x 2		. . .			
Time frame 3	MELPe			. . .			
Time frame 4	MELPe			. . .			
. . . .							
Time frame N	MELPe			. . .			
Time frame N+1	DR	DC x 2		. . .			
Time frame N+2	DC x 2	Released		. . .			

Review of the NBWF Link Layer (STANAG 5632)



Basic NBWF Physical Layer Implementation

- Basic NBWF PHY Layer Implementation by the Communications Research Center (CRC) in Canada
- Implementation in Visual Studio (Windows)
- Transmitter control object class modulates by the NBWF waveform a vector of bits into IQ samples by the NBWF waveform
- Receiver control object class demodulates by the NBWF waveform IQ samples into a vector of bits

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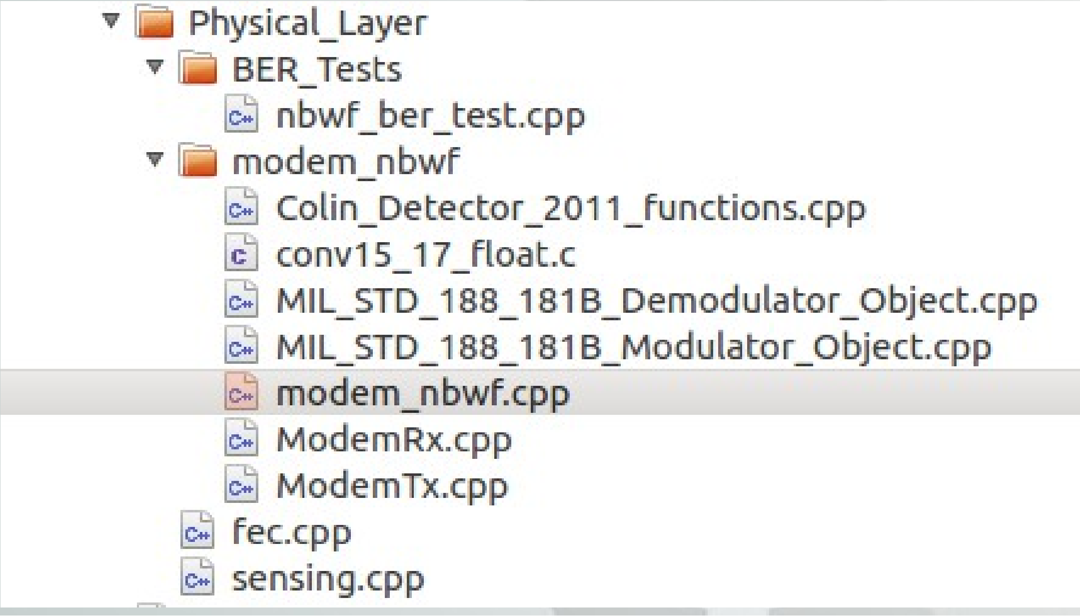
Advanced NBWF Physical Layer Implementation for low-cost SDR platforms

- Qt: a cross-platform application framework for developing application software with a graphical user interface.
- IT++: A C++ library of mathematical, signal processing and communication classes and functions.
- The Basic NBWF Physical Layer Implementation has been ported from Visual Studio to Qt and IT++.
- Transmitter and Receiver control object classes have been converted in modem_nbwf. nbwf_ber_test allows to test BER of the waveform.



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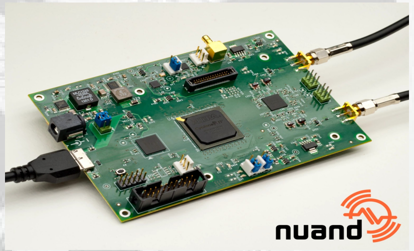
Advanced NBWF Physical Layer Implementation for low-cost SDR platforms

- Receive only SDR:
  - RTL-SDR (Range: 22MHz-2.2GHz, Bandwidth: 3.2 MHz, 20 euros)
  - Other SDR receivers: Funcube Dongle, etc.
- Transmit and receive SDR:
  - USRP (Range:DC-6GHz, Bandwidth: 56 MHz, 700-5000 euros, Full-Duplex)
  - HackRF (Range: 30MHz-6GHz, Bandwidth: 20 MHz, 300 euros, Half-Duplex)
  - BladeRF (Range: 300MHz-3.8GHz, Bandwidth: 28 MHz, 400 euros, Full-Duplex)





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Advanced NBWF Physical Layer Implementation for low-cost SDR platforms

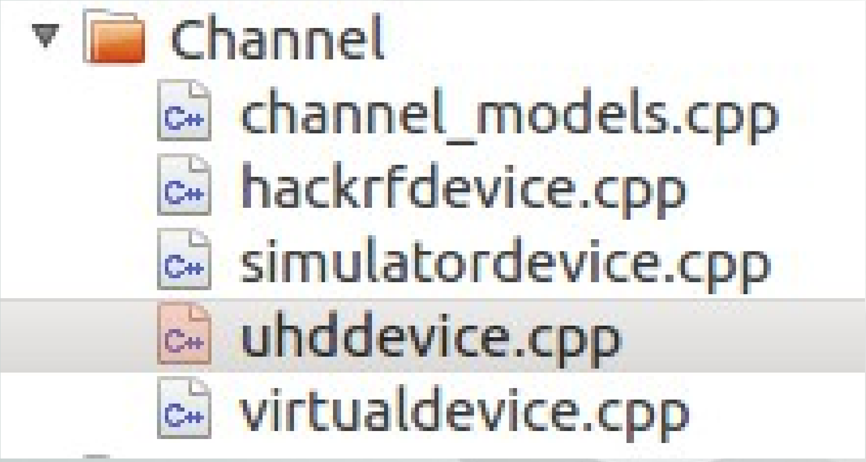
- Connect the NBWF modem to the SDR platforms using the UHD, HackRF C++ API (GNU Radio C++ API is also possible) to read and send samples in real-time
  - Example: Send samples of an IT++ complex vector with UHD C++ API

```
void UHDDevice::sendsamples(cvec tx_buff,double timestamp){

    double tx_rate=1.0e6;
    uhd::tx_metadata_t tx_md;
    tx_md.start_of_burst = true;
    tx_md.end_of_burst = true;
    tx_md.has_time_spec = true;
    tx_md.time_spec = uhd::time_spec_t(timestamp);
    tx_stream->send(&tx_buff(0), tx_buff.size(), tx_md, timestamp+tx_bu
```

Advanced NBWF Physical Layer Implementation for low-cost SDR platforms

- The NBWF modem class can be connected to:
  - UHD Device class for USRP hardware
  - HackRF Device class for HackRF hardware
  - Virtual Device class (emulation of hardware device)
  - Simulator Device class (simulation of high number of nodes)
- Virtual Device and Simulator Device classes can use multiple channel models (Free Space, COST 207, ITU, SUI) for realistic channel environments (includes transmit power, frequency, speed, sampling rate).



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NBWF Link Layer Implementation

- Development of a Point-to-Point FDD class, a Point-to-Point TDD class, a TDMA class for link layer tests
- Development of a NBWF TDMA class (9 slots of 22.5 ms = 202.5 ms)
- Performance tests with Simulator Device class for high number of nodes

- Data_Link_Layer
  - Performance_Tests
    - nbwf_tdma_performance_test.cpp
    - point_to_point_fdd_performance_test.cpp
    - point_to_point_tdd_performance_test.cpp
    - tdma_tdd_performance_test.cpp
  - nbwf_tdma_rx.cpp
  - nbwf_tdma_tx.cpp
  - point_to_point_fdd_rx.cpp
  - point_to_point_fdd_tx.cpp
  - point_to_point_tdd_rx.cpp
  - point_to_point_tdd_tx.cpp
  - tdma_tdd_rx.cpp
  - tdma_tdd_tx.cpp

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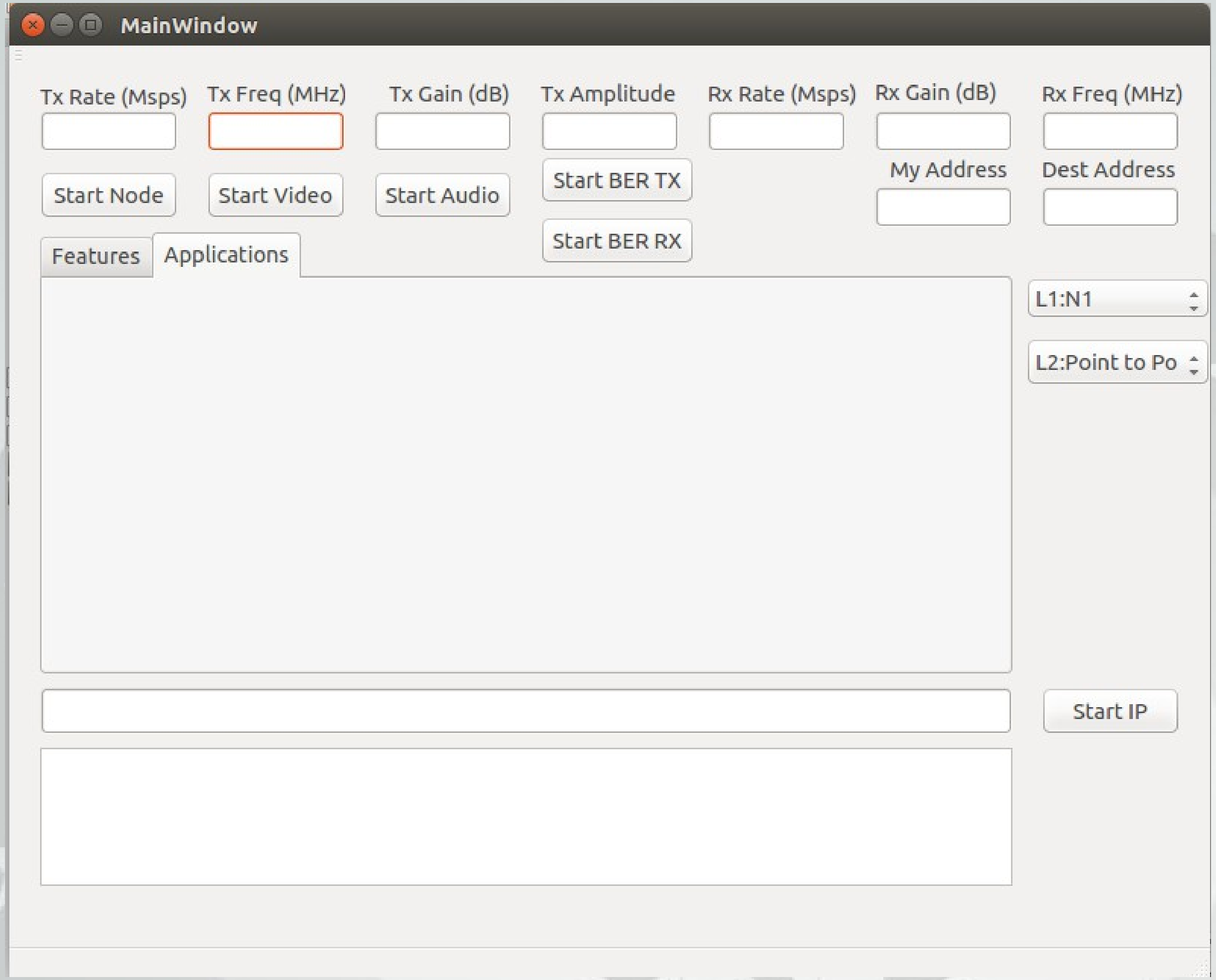
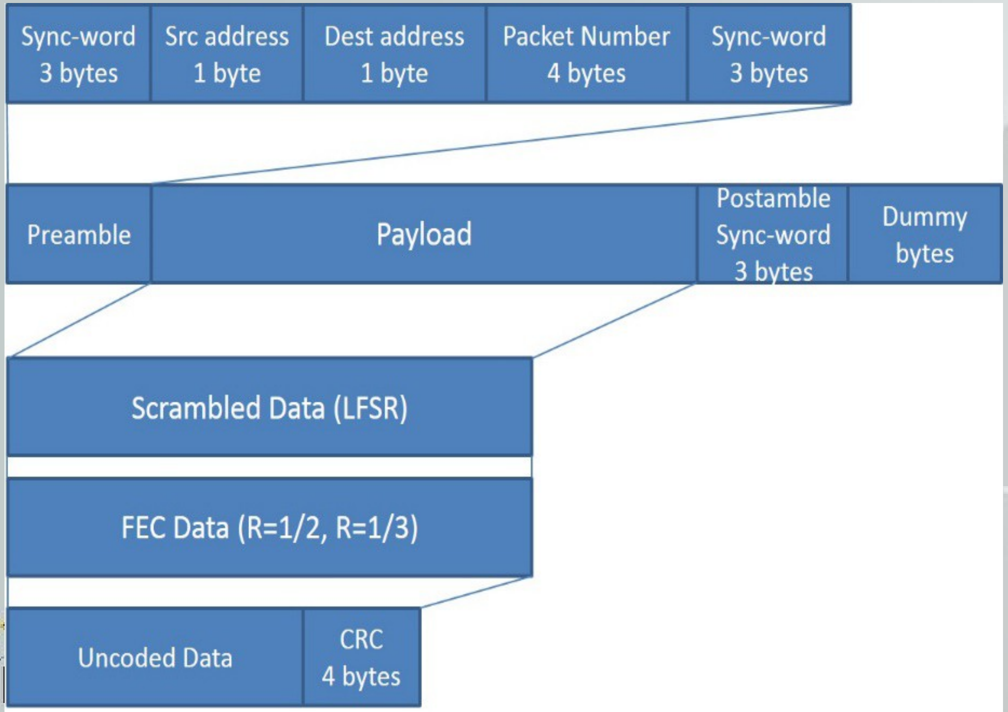
Real-time Qt Application for NBWF

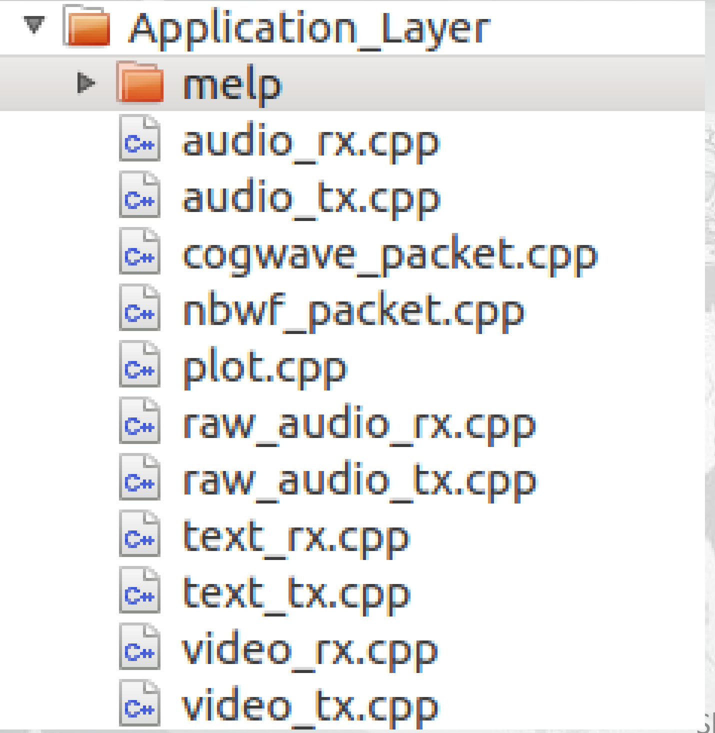
- Physical Layer (L1): select NBWF modes N1, N2, N3, N4, N5, N6, NR
- Parameters to control Tx and Rx rate, frequency, gains
- Link Layer (L2): select Point-to-Point TDD, Point-to-Point FDD, TDMA, NBWF TDMA
- Several applications (Video (M-JPEG), Audio (MP3 or MELPe, BER, Text message, IP traffic)
-



Real-time Qt Application for NBWF

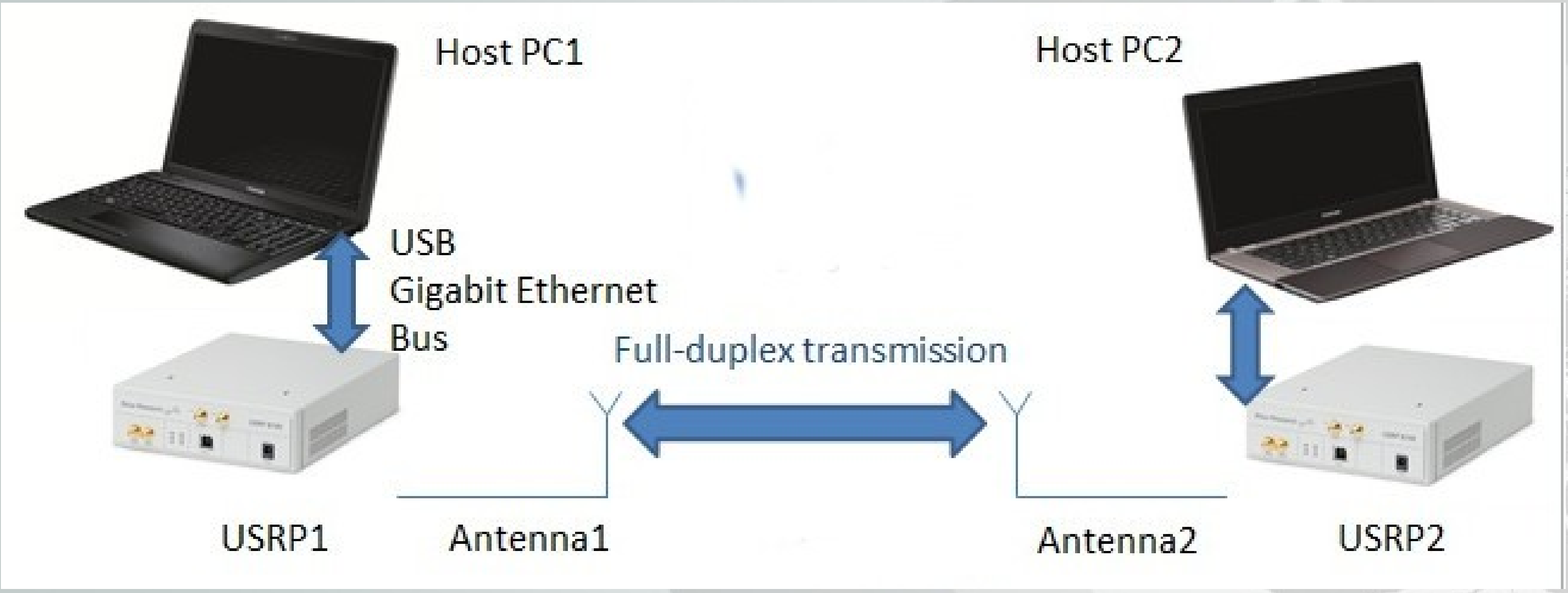
- Tests using custom slot size for our own applications (Audio MP3, Video M-JPEG, BER, Text Message, IP traffic)
- Tests using NBWF slot size (22.5 ms) for MELPe audio application and IP traffic



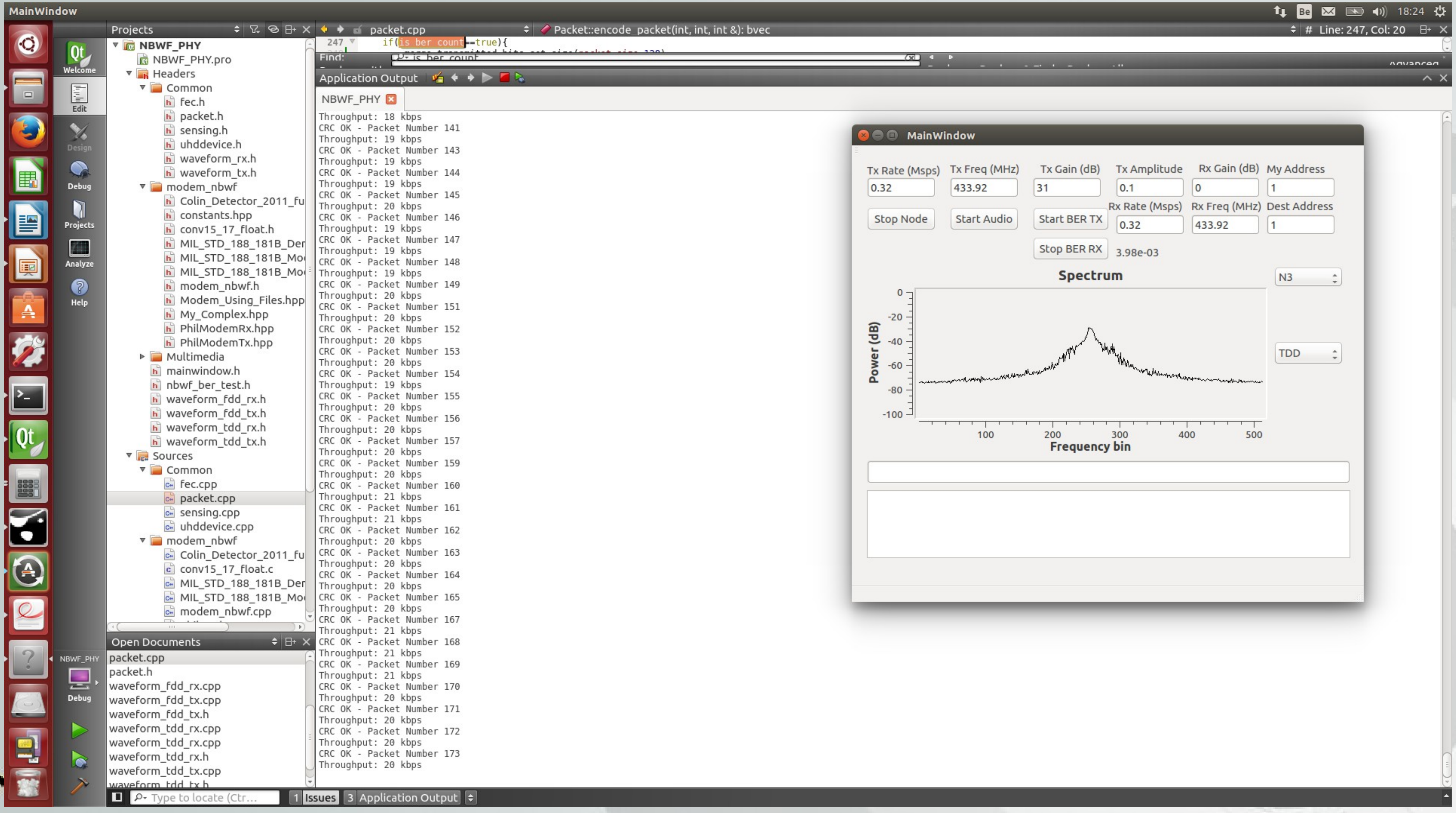


Real-time Qt Application for NBWF

- Demonstration of the Qt NBWF application using 2 laptops, 2 USRPs .



Real-time Qt Application for NBWF



Lessons learned

- A few months to develop a real-time Qt application that will transmit and receive using the UHD C++ API
- A few weeks to port the basic NBWF PHY implementation (BER only in Visual Studio) to the real-time Qt application. If NBWF PHY implementation had to be implemented from scratch, it would take about six months.
- A few weeks to develop a voice application using MELPe in the real-time Qt application.
- A few months to develop a basic MAC for Connection Request, Connection Confirm and MV transmission.
- The advantage of a USRP device compared to other devices is that physical layer sample rates match STANAG 5631 (flexible master clock rate).

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Conclusions and future work

- Conclusions
  - Implementation of NBWF Physical Layer
  - Implementation of some parts of the NBWF Link Layer
- Future work
  - Continue on the implementation of the NBWF Link Layer (STANAG 5632)
  - Implementation of the NBWF Network Layer (STANAG 5633)
  - Possibility to use the NBWF as a basic waveform in the EDA Cat B MAENA project for the VHF link
  - Possibility to use this work for a NATO reference implementation