HNAP4PlutoSDR - HAMNET on 70cm with the PlutoSDR

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*The project "NPR - New Packet Radio" by Guillaume, F4HDK, has revived the German 200 kHz duplex channel in the 70 cm amateur radio band. There is now a further possibility to realize higher data rates when accessing HAMNET on 70 cm with the implementation of the "**H**AM**N**ET **A**ccess **P**rotocol" for the ADALM Pluto SDR.*

The VHF/UHF/SHF department of the German Amateur Radio Club (DARC) has been working several years to activate the duplex frequency 439.700 MHz (node) / 434.900 MHz (user) with 200 kHz bandwidth each for access to the HAMNET in the 70 cm band [1]. Especially for HAMNET-interested persons without "line-of-sight" conditions to the next HAMNET-node, it opens a possibility to participate in HAMNET via radio. At the end of last year, the VHF/UHF/SHF department, in coordination with the Federal Network Agency, redefined the conditions how the duplex channel can be used. As the first non AX.25-based solution, the project "NPR - New Packet Radio" by Guillaume, F4HDK, has triggered a new wave of activity. Some HAMNET nodes have already been upgraded for duplex operation of 439.700 MHz TX / 434.900 MHz RX and serve the channel with NPR.

A new flexible method based on SDR technology

Christian, DL1COM, and Jann, DG8NGN, supervised a thesis with the topic "Design of a Radio Communications Protocol for HAMNET Access in the 70cm Amateur Radio Band" at their employer. Lukas Ostendorf, a Master's student at the Institute for Networked Systems at the RWTH Aachen University, took up the challenge and completed his Master's thesis at Rohde & Schwarz in Munich. The result is the HAMNET Access Protocol (HNAP), which was implemented on the ADALM Pluto SDR platform (HNAP4PlutoSDR).

Overview of the system requirements

The system to be developed should meet several requirements:

- several users should be able to make VoIP calls with sufficient quality in parallel
- the usable data rate should increase with higher signal quality
- a connection should also be possible without direct view to the HAMNET node (for "line-of-sight" conditions, higher frequency bands are already available)
- legal requirements must be met (no encryption, compliance with the spectral mask, naming the callsign, …)
- the system has to work transparent on the Ethernet level (OSI layer 2)
- the costs should be in the low three-digit range, especially on the user side
- an open system architecture should give room for future developments (open source)
- the barrier to use the system should be kept low

Description of the system design

The HAMNET base station operates in the 70 cm upper band and transmits at 439.700 MHz, while users share input at 434.900 MHz in TDMA mode. The System uses OFDM modulation with 64 subcarriers and 4 kHz subcarrier spacing. 40 of these subcarriers are modulated with QPSK, QAM-16, QAM-64 or QAM-256 [Fig. 1].

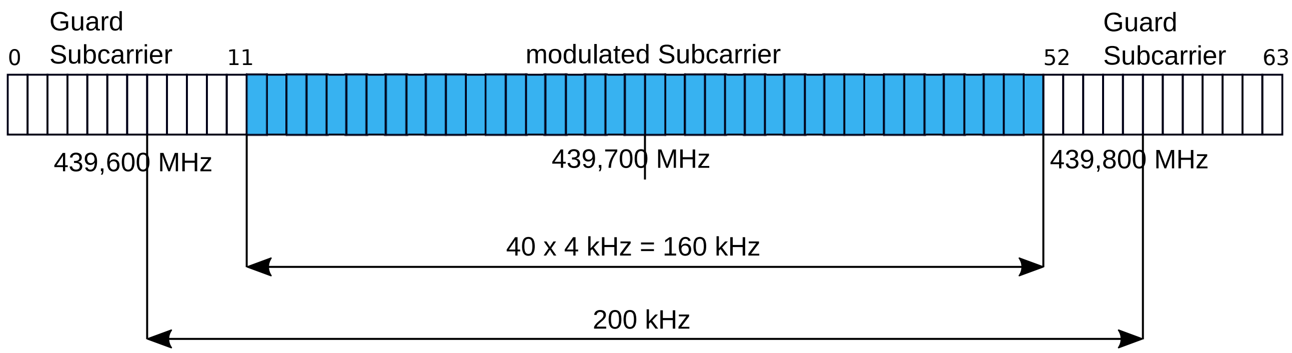

Figure 1: Modulated subcarriers are showed in blue

Twelve unmodulated guard subcarriers are defined on the left and right, so that the spectral mask according to ITU Recommendation SM.1541 Annex 9 [1] will be met [Figure 2].

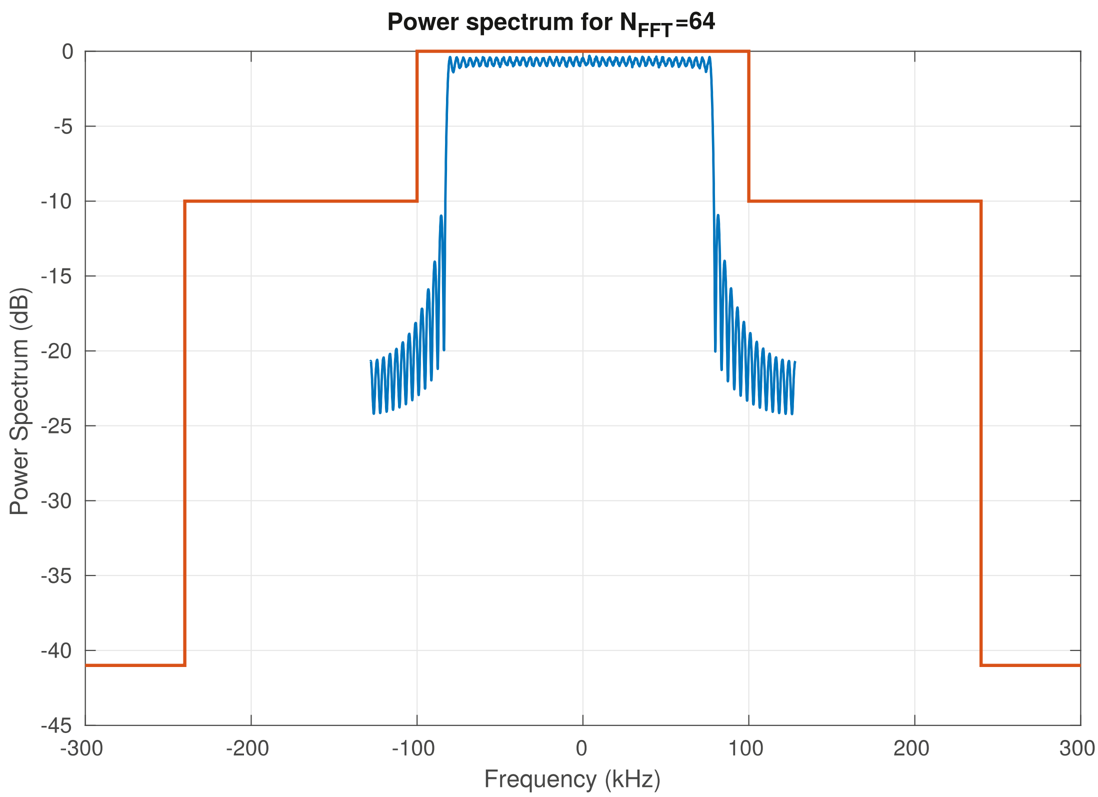

Figure 2: Simulated OFDM spectrum with spectral mask according to SM.1541 Annex 9

On the time axis 512 OFDM symbols (= 136ms) are defined in one frame. A frame consists of eight subframes each with 64 OFDM symbols (= 17ms). The uplink and downlink frames are shifted in time relative to each other [Fig. 3].

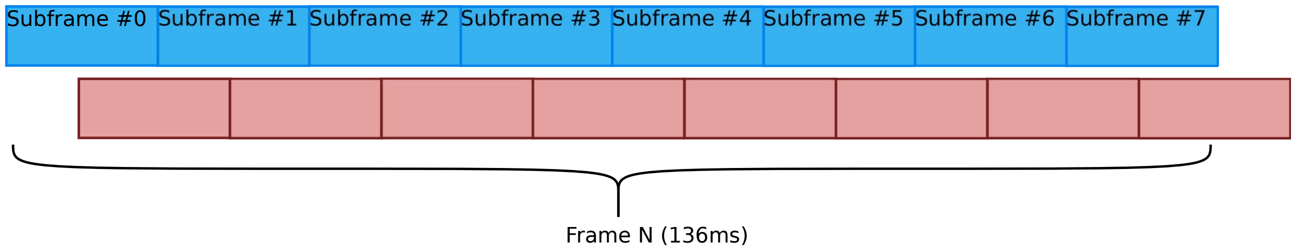

Figure 3: Timing of the frames in the downlink (blue) to the uplink (red)

A subframe consists of slots of the types "Synchronization", "Downlink Control", "Uplink Control", "Downlink Data", "Uplink Data" and "Random Access" with different lengths [Figure 4].

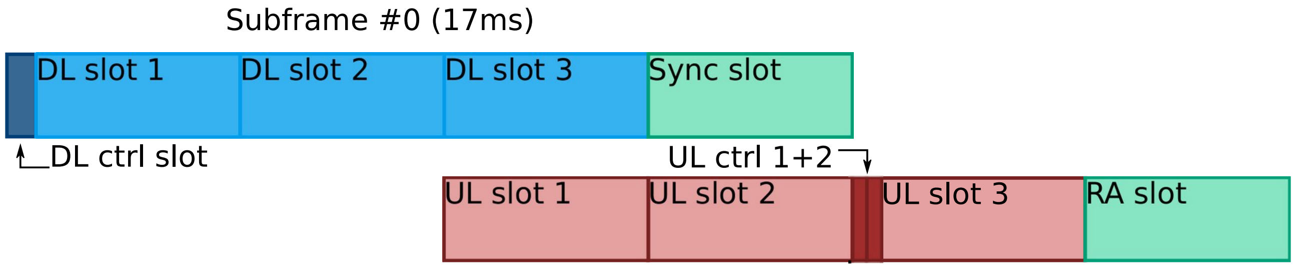

Figure 4: The first subframe of each frame accommodates all occurring slot types

During a data transmission most OFDM symbols are used for slots with the type "Downlink Data" and "Uplink Data". Those can be modulated with higher modulation and convolutional coding schemes depending on the signal to noise ratio. Only a few OFDM symbols are used for the remaining control slots. They are always modulated with QPSK and encoded using coding rate 1/2 (MCS0) [Table 1]. This ensures high robustness against interference.

MCS idx	modulation	coding rate	logical channel size
0	QPSK	1/2	62
1	QPSK	3/4	93
2	16QAM	1/2	125
3	16QAM	3/4	187
4	64QAM	1/2	188
5	64QAM	3/4	282
6	256QAM	1/2	250

Table 1: Modulation & Coding Scheme for slots of the type "Downlink Data" and "Uplink Data"

In the "Downlink Data" and "Uplink Data" slots, a logical channel for the transmission of MAC messages of type "Data" and "Control" is defined and secured with a CRC16 checksum [Figure 5].

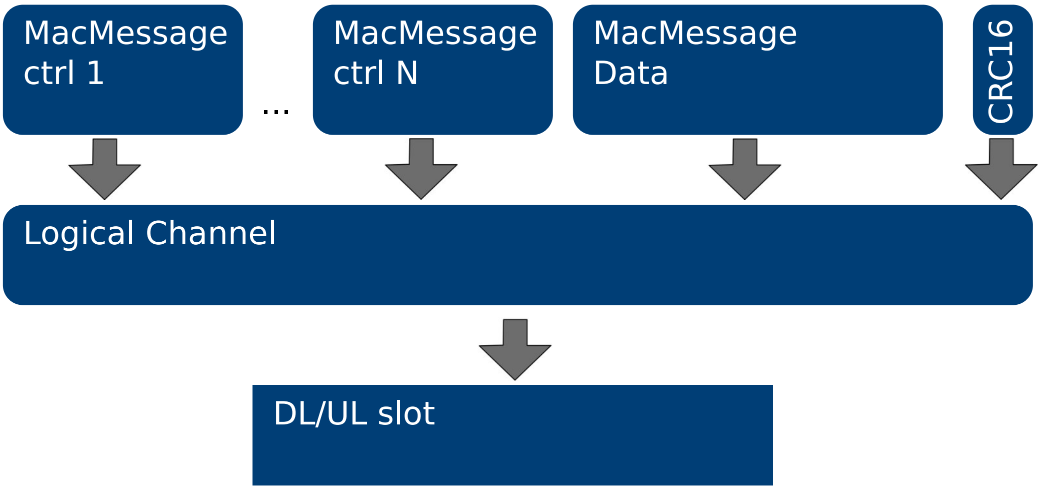

Figure 5: The Ethernet frames or their fragments are transmitted in the data channel of a MAC message

The exact definitions of the PHY and MAC layers can be found in the appendix of the master thesis [2]. Together with the chapter "System Design" they form the definition of the **H**AM**N**ET **A**ccess **P**rotocol (HNAP) [3].

Implementation on the ADALM Pluto

The ADALM Pluto SDR comes with an integrated Linux operating system, which has proven to be a good choice for implementation. Detached from the home PC, it can be operated like a classic HAMNET transceiver for 13 or 6 cm with the help of a USB-OTG connection and a USB-LAN adapter.

The block diagram [Figure 6] provides a system overview of the implementation.

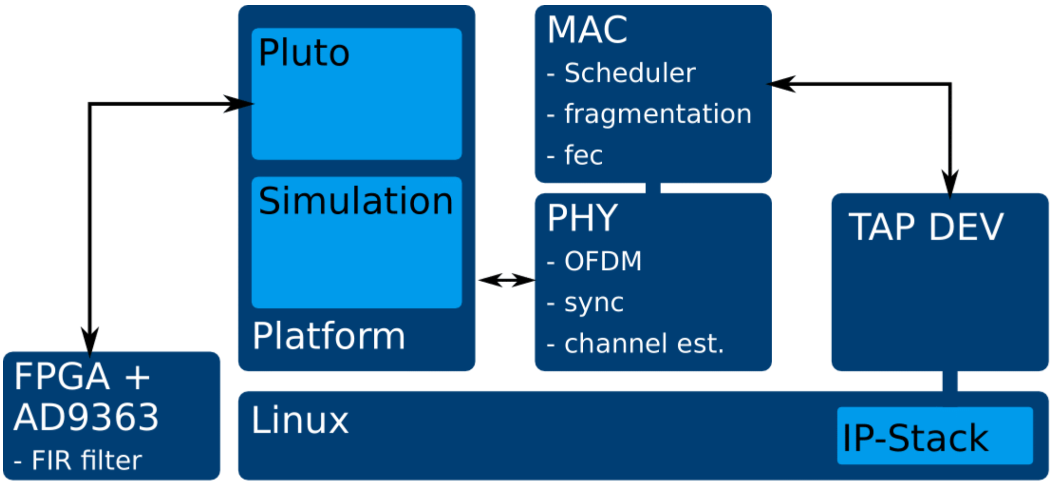

Figure 6: The block diagram shows the PHY and MAC layers

The application itself uses several threads to process the individual tasks. The requirement to fill the buffers in time is quite high. For this reason, a real-time kernel was used and the time-critical processes "PHY TX" and "PHY RX" are running on the second, isolated CPU core [Figure 7].

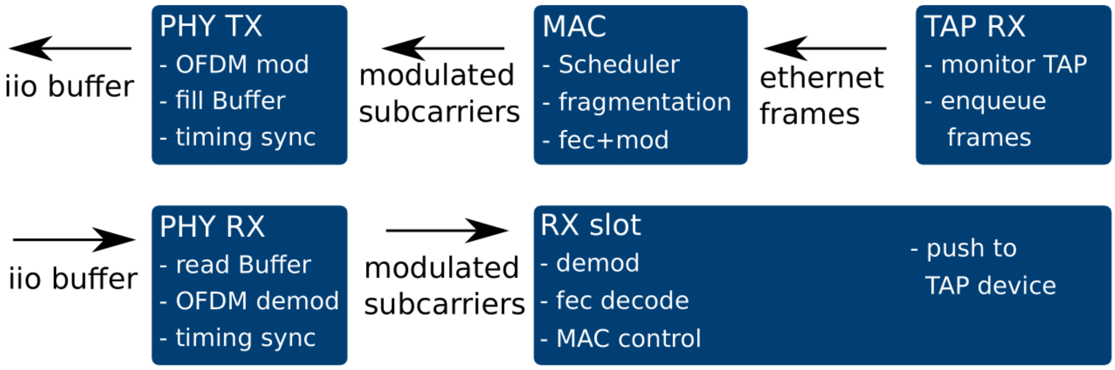

Figure 7: Communication between the threads

Brief description of the setup in the laboratory

The following steps are necessary:

- Download the HNAP4PlutoSDR firmware image (pluto.frm) from [2]
- Flash the image to the PlutoSDR (Drag&Drop from PC to Pluto)
- Initial system configuration (switching on the second CPU core, IP addresses, callsign, operating mode)
- Start of the application at the user's site

More detailed instructions can be obtained from the project homepage http://hnap.de [3].

Important notes:

- The OFDM modulation method initially requires a high frequency stability and a good estimation of the frequency deviation. The oscillator built into the PlutoSDR, with its 25 ppm absolute deviation and its great dependence on temperature fluctuations, is too imprecise for stable operation. At least the base station needs a more stable TCXO. We strongly recommend to replace it even at the user's site. We have chosen the "Epson TG-5006CJ-51H".
- The antennas supplied with the ADALM Pluto are not suitable for the 70 cm frequency band and must be replaced by suitable antennas even in the laboratory setup. Otherwise the effect is that harmonics of the signal will propagate or be received better than the 70 cm fundamental wave via the supplied antennas. Due to the receiver principle, the estimation of the frequency deviation can fail as a result. Details can be found in chapter "5.2.3 - Issues with the carrier synchronization" of the master thesis [2].

Current status of the project

Thanks to the optimized Viterbi decoder ported by Lukas to the CPU platform of the ADALM Pluto, the system can use up to QAM-256 modulated OFDM subcarriers. However, depending on the code rate, the performance limit of the CPU is exceeded, so that decoding cannot be performed in the required time. Practical data rates greater than 350 kbps however are feasible [Table 2].

MCS idx	UDP segment size	UDP data rate
0	1408	86 kbps
1	1366	130 kbps
2	1398	184 kpbs
3	1414	284 kpbs
4	1422	284 kpbs
5	1343	434 kbps
6	1428	380 kbps

Table 2: Data rates measured with "iperf" with optimum selection of UDP packet lengths

A system test in which different users operated with different MCS has shown the expected data rates.

The measured output power is about 0 dBm. The emission meets the requirements of the spectral mask [Fig. 8].

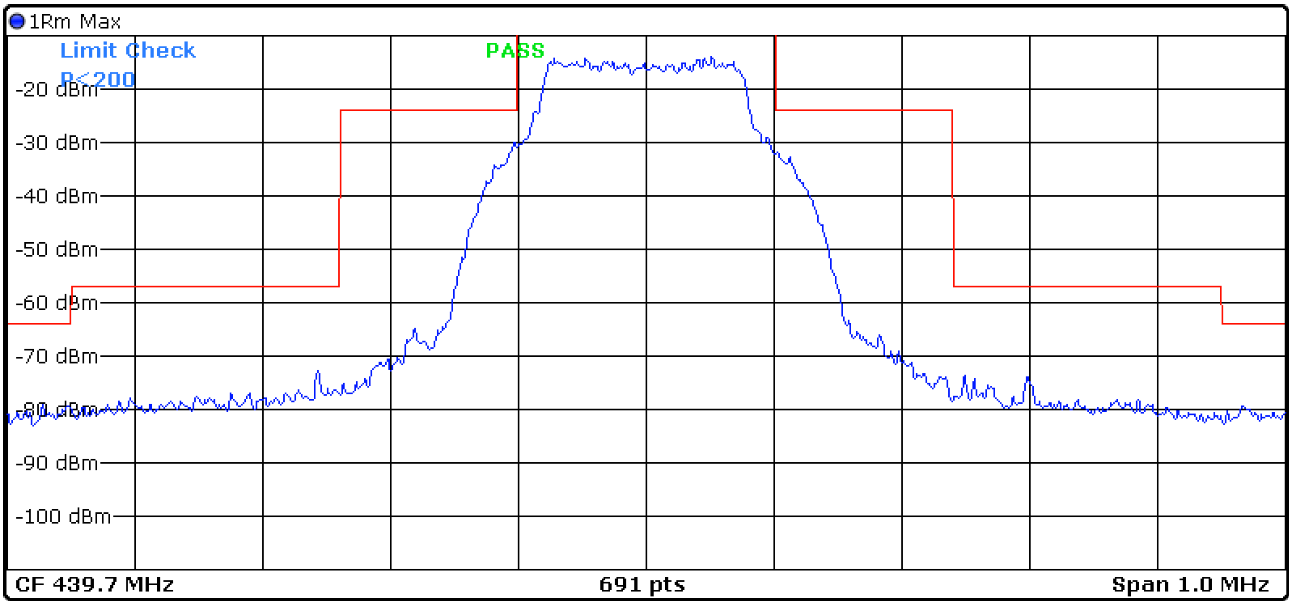

Figure 8: Measured OFDM spectrum with spectral mask according to SM.1541 Annex 9

Outlook

The way from the laboratory setup to real world deployments still requires a few steps. Especially a sufficient power amplification is a hurdle in our targeted application due to the lack of direct line of sight. Since the peak-to-average power ratio is quite high with the selected OFDM method, linear power amplifiers are required. There are some ideas to replace the PHY layer with a "single-carrier" alternative (with lower linearity requirements for the power amplifier), however it requires some effort.

The project can now be continued within our amateur radio community. There are some examples you can participate on:

- Development of a suitable power amplifier with practical tests over longer distances (the keying of a power amplifier using GPIO is already implemented)
- Work on a "single-carrier" solution
- Extension to use different HF bandwidth in the up- and downlink
- Making use of the FPGA to reduce load on the main CPU
- General work on program code and documentation

Conclusion

The project HNAP4PlutoSDR is a candidate to enable higher data rates for HAMNET user access points in the 70 cm band. The open program code and the documentation based on a master's thesis will help us to move on to a real world deployment.

[1] https://www.itu.int/rec/R-REC-SM.1541
[2] https://github.com/hamnet-access-protocol
[3] http://hnap.de