A LTE Receiver Framework Implementation in GNU Radio

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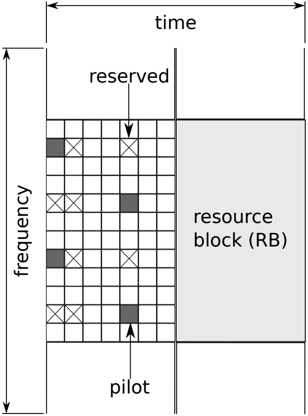
Contents

LTE overview

Air interface basics (downlink)

- OFDM signal (15 kHz subcarrier bandwidth)
- different modes possible
  - variable bandwidth (up to 20 MHz)
  - MIMO capabilites (up to 4x4)
- 6 physical channels
  - 3 transport channels
  - 3 control information channels



Roadmap

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Tasks

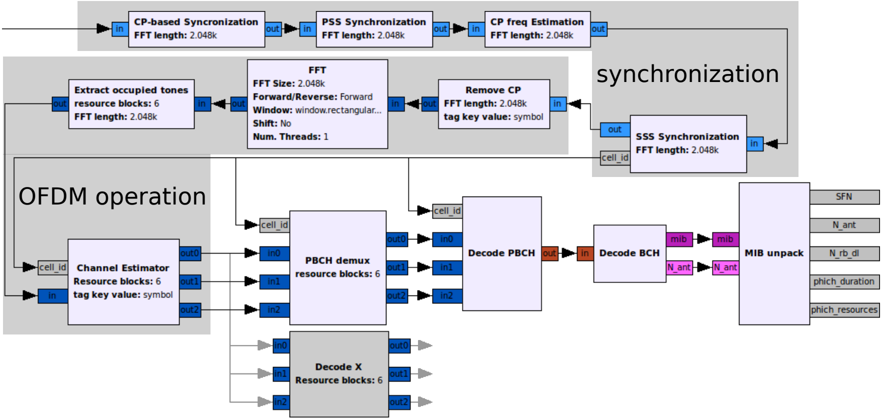
- synchronization
  - time, frequency, frame timing
- OFDM operation
  - radio channel estimation, equalization
- demodulation
  - STBC, FEC
  - physical channel demultiplexing
- extract system parameters
  - cell ID
  - MIMO configuration
  - system bandwidth

Implementation goals

- modular block-based structure
- separate handling of data and control information
- use stream- and event-based processing

Implementation overview

Receiver framework components at work: Example flowgraph with MIB decoding



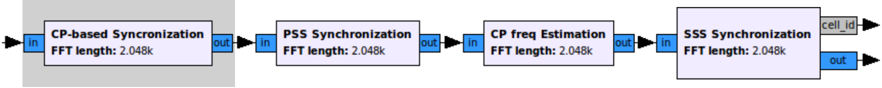
Synchronization

cyclic prefix (CP)-based synchronization

- recover coarse symbol timing $\hat{n}_0$
- calculate sliding window correlation with fixed lag of N_{FFT}

$$\hat{n}_0 = \arg\max_n |\gamma(n)|\,,\ \gamma(n) = \sum_{m=n}^{n+N_{\mathrm{CP}}-1} r(m)\, r^*(m - N_{\mathrm{FFT}})$$

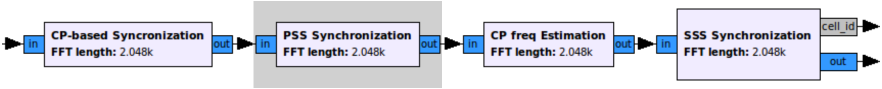
- stream tags
  - tags indicate symbol start



Synchronization

primary synchronization symbol (PSS) detection

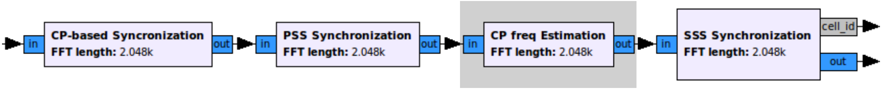
- recover fine symbol timing and half-frame timing
- extract cell ID number N_{ID2} from PSS
- stream tags
  - indicate half-frame start
  - propagate cell ID number N_{ID2}



Synchronization

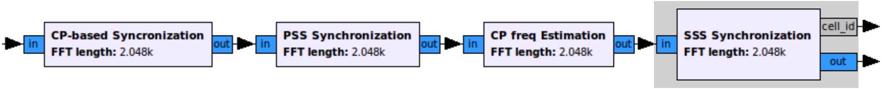
frequency offset detection and correction

- recover fractional frequency offset
- half-frame timing needed
  - different CP-lengths within each slot



Synchronization

- secondary synchronization symbol (SSS) detection
  - recover frame timing
  - extract cell ID group N_{ID1}
- receive N_{ID2} tag
  - calculate cell ID $N_{\mathrm{ID}} = 3 * N_{\mathrm{ID1}} + N_{\mathrm{ID2}}$
- message port
  - publish N_{ID} for dynamic block configuration
- stream tags
  - indicate frame start



OFDM operation

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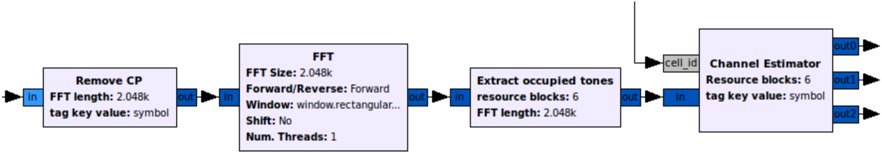
inverse OFDM operation

- remove cyclic prefix
- compute FFT
- extract subcarriers of interest
  - complexity reduction

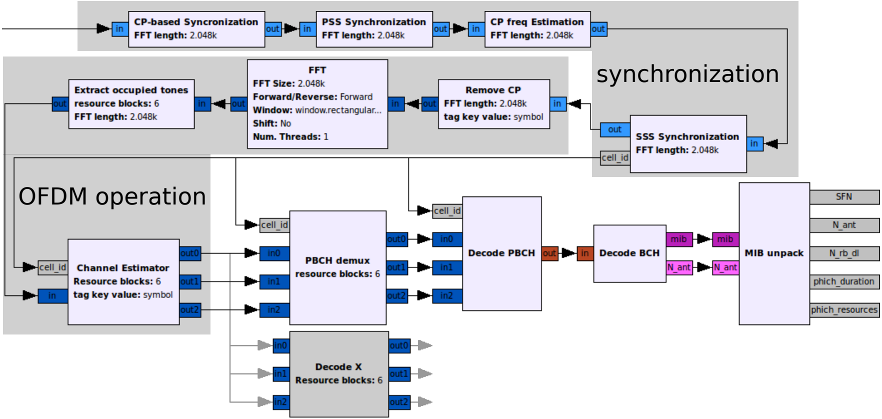
channel estimation

- get pilot positions
- calculate channel coefficients
- linearly interpolation
- output data stream and channel estimates for antenna port 0 and 1



Implementation overview

Receiver framework components at work: Example flowgraph with MIB decoding



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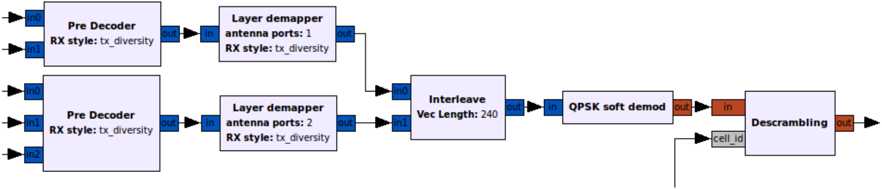
Decode PBCH

- MIMO configuration still unknown at this point
  - trail & error: different configurations interleaved in output
- inverse Alamouti Operation
- deinterleave layers
- demodulation: PBCH always uses QPSK
- descrambling
  - scrambling sequence depends on N_{ID}



Decode BCH

- BCH is transmitted on PBCH
- Deinterleaving (block-based)
- Viterbi decoder
  - hierarchical block
  - parameterized GNU Radio Viterbi decoder
- Calculate CRC
  - CRC checksum depends on MIMO configuration
  - CRC match indicates number of TX antennas

Implementation overview

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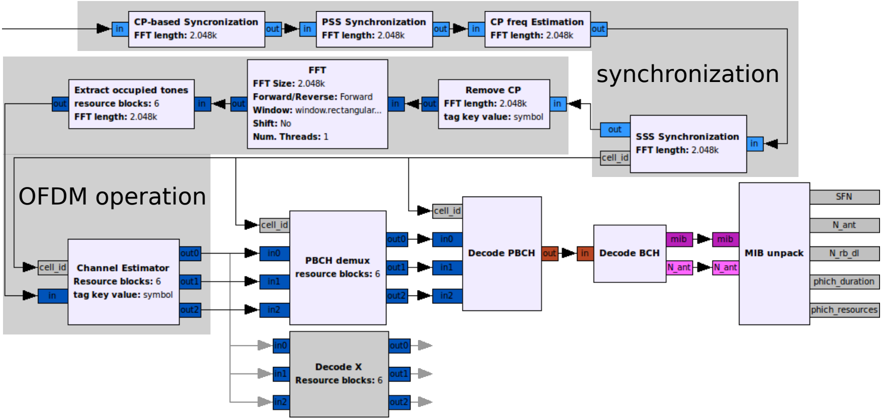
Receiver framework components at work: Example flowgraph with MIB decoding



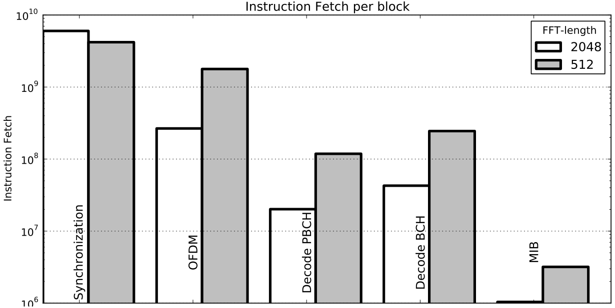
Test with recorded data

- IQ baseband samples as input
  - recorded using a USRP N210
- flowgraph output
  - fixed parameters
    - MIMO: 2x1
    - RB: 50 equals 10 MHz
    - PHICH parameters
  - system frame number
- decoding rate 97.8%
- tests indicate real time capabilities

```
SFN = 821       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 822       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 823       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 824       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 825       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 826       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 827       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 828       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
freq_estimate_c ASYNC!  new offset = 3250       old offset = 3251       samp_num = 14177
SFN = 829       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 830       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 831       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 832       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 833       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 834       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 835       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 836       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 837       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 838       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 839       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 840       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 841       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 842       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 843       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 844       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 845       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 846       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
SFN = 847       diff = 1        (N_ant=2 N_rb_dl=50 PHICH: dur=0 res=1,00)
mib_unpack_vb   decoding_rate = 0,978
```

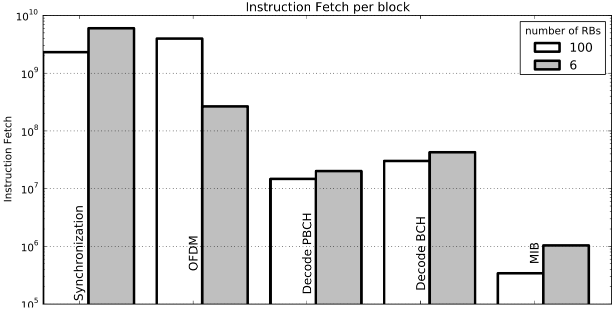
Effect of sample rate on performance

- varying sample rate
  - FFT-length depends on sample rate
- relative performance changes
- lower sample rate
  - less multiplications
  - smaller correlation sequences
  - smaller FFT-length



Effect of computed resource blocks on performance

- varying number of RBs
  - FFT-length always 2048
  - number of RBs limited by FFT-length
- channel estimation is more complex
- great increase of power consumption in OFDM part



Conclusion

- LTE overview
- introduction to our GNU Radio LTE receiver
  - synchronization, OFDM operation, PBCH extraction
  - example output
- performance analysis
  - different parameters
- possibilities
  - Detect LTE cells with parameters
- What's next
  - extend flowgraph with additional channels and uplink
- source code available at `github.com/kit-cel/gr-lte`

The End

Thanks for your attention!

gr-lte source code available at `github.com/kit-cel/gr-lte`