A LTE Receiver Framework Implementation in GNU Radio

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LTE overview

Air interface basics (downlink)
- OFDM signal (15 kHz subcarrier bandwidth)
- different modes possible
  - variable bandwidth (up to 20 MHz)
  - MIMO capabilities (up to 4x4)
- 6 physical channels
  - 3 transport channels
  - 3 control information channels
Roadmap

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 $N_{\text{FFT}}$

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

- 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 $N_{ID} = 3 \times N_{ID1} + N_{ID2}$
- message port
  - publish $N_{ID}$ for dynamic block configuration
- stream tags
  - indicate frame start
OFDM operation

- 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

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Implementation overview

Receiver framework components at work: Example flowgraph with MIB decoding
Decode PBCH

- MIMO configuration still unknown at this point
  - trial & 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

Receiver framework components at work: Example flowgraph with MIB decoding

OFDM operation

Channel Estimator
Resource blocks: 6
tag key value: symbol

PBCH demux
Resource blocks: 6

Decode PBCH

Decode BCH

MIB unpack

SSS Synchronization
FFT length: 2.048k

Remove CP
FFT length: 2.048k
tag key value: symbol

Extract occupied tones
resource blocks: 6
FFT length: 2.048k

CP-based Synchronization
FFT length: 2.048k

PSS Synchronization
FFT length: 2.048k

CP freq Estimation
FFT length: 2.048k

synchronization

SFN
N_ant
N_rb_dl
phich_duration
phich_resources
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
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

![Graph showing Instruction Fetch per block with FFT-length as 2048 and 512]
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

![Instruction Fetch per block graph]

- Synchronization
- OFDM
- Decode PBCH
- Decode BCH
- MIB

Number of RBs:
- 100
- 6
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
Thanks for your attention!

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