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XXXV Cycle

Single Frequency Network Terrestrial Broadcasting with 5GNR numerology using Recurrent Neural Network

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Research context and motivation

- Single Frequency Network (SFN) Terrestrial Broadcasting
  - All stations transmit signal at the same time over the same frequency channel
  - Orthogonal Frequency Division multiplexing (OFDM)
  - Symbol by symbol detection
  - CP length increases with Inter Site Distance (ISD)
  - Symbol length reduces with user speed
  - DVB-T2 & ASTC 3.0
- The LTE-based Terrestrial Broadcasting
  - Dedicated for Terrestrial Broadcasting (2.5 kHz and 0.37 kHz)
  - Mobile handheld users and roof-top reception
- The fifth generation New Radio (5GNR)
  - 15 kHz, …, and 240 kHz carrier spacing
  - Uni-cast and low latency transmission (Maximum ISD 5 km)
  - Not compatible with broadcaster infrastructures (short CP length 4.7μs)

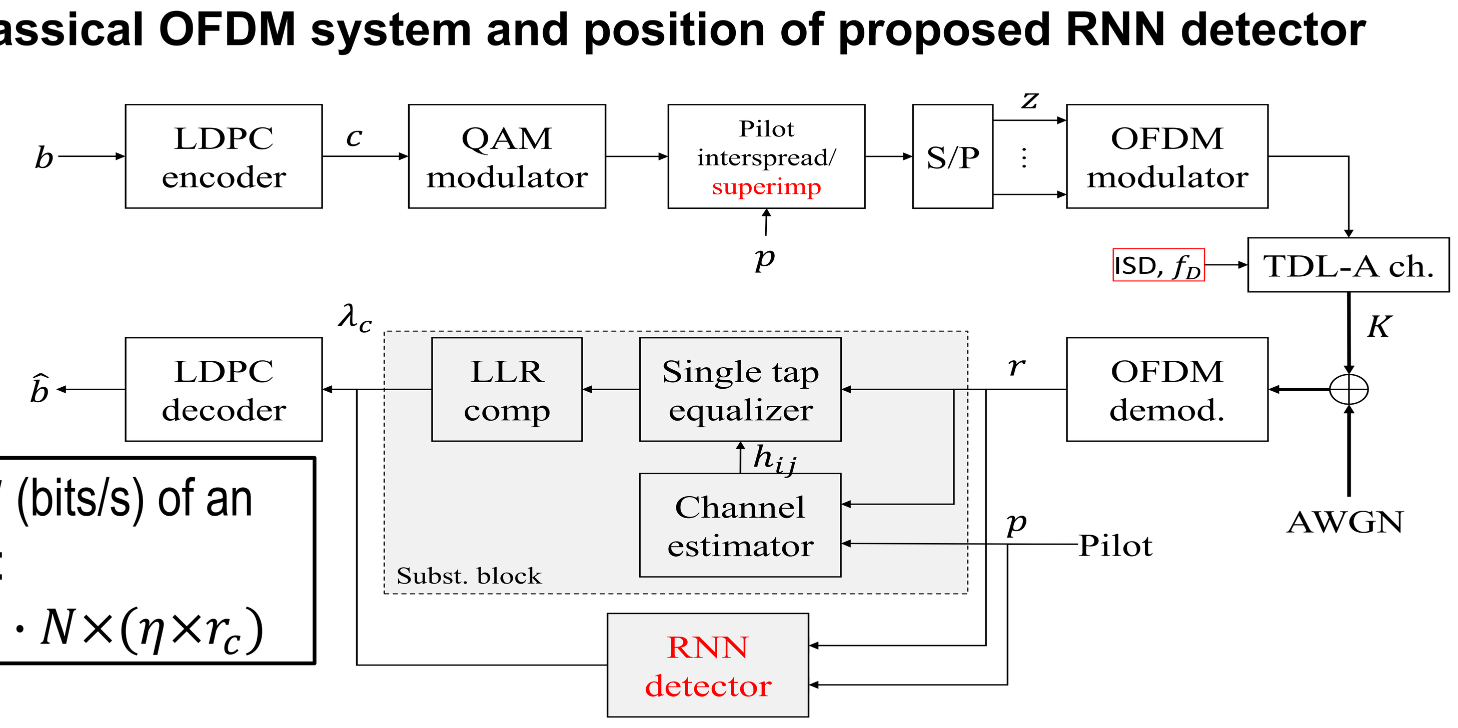
Addressed research questions/problems

- Modelling an SFN network with Tap Delay Line (TDL-A)
  - Properly scaling maximum delay spread according to the considered ISD
  - Carrier frequency 700 MHz
  - Maximum Doppler shift 130 Hz (160 km/h)
  - Single Frequency networks
    - High Power High Tower (HPHT)
    - Low Power Low Tower (LPLT)

SFN Parameters

Parameter	LPLT	HPHT
ISD [km]	15	125
DS [μs]	20	50

The classical OFDM system and position of proposed RNN detector



Throughput T (bits/s) of an OFDM system:
$T = R_s \times n_b \cdot N \times (\eta \times r_c)$

- The OFDM design for SFN networks becomes progressively inefficient
  - Trade-offs between CP length, channel delay spread, carrier spacing a user mobility
  - To remove ISI, the CP larger than the delay spread (DS)
  - To remove ICI, symbol smaller than channel coherence time
  - Pilots introducing a large overhead
- To support 5GNR numerologies for Terrestrial broadcasting
  - An advanced OFDM detector capable of dealing with large ISI/ICI
  - May eliminate the CP inefficiency, but cannot eliminate inefficiency due to the required pilot density

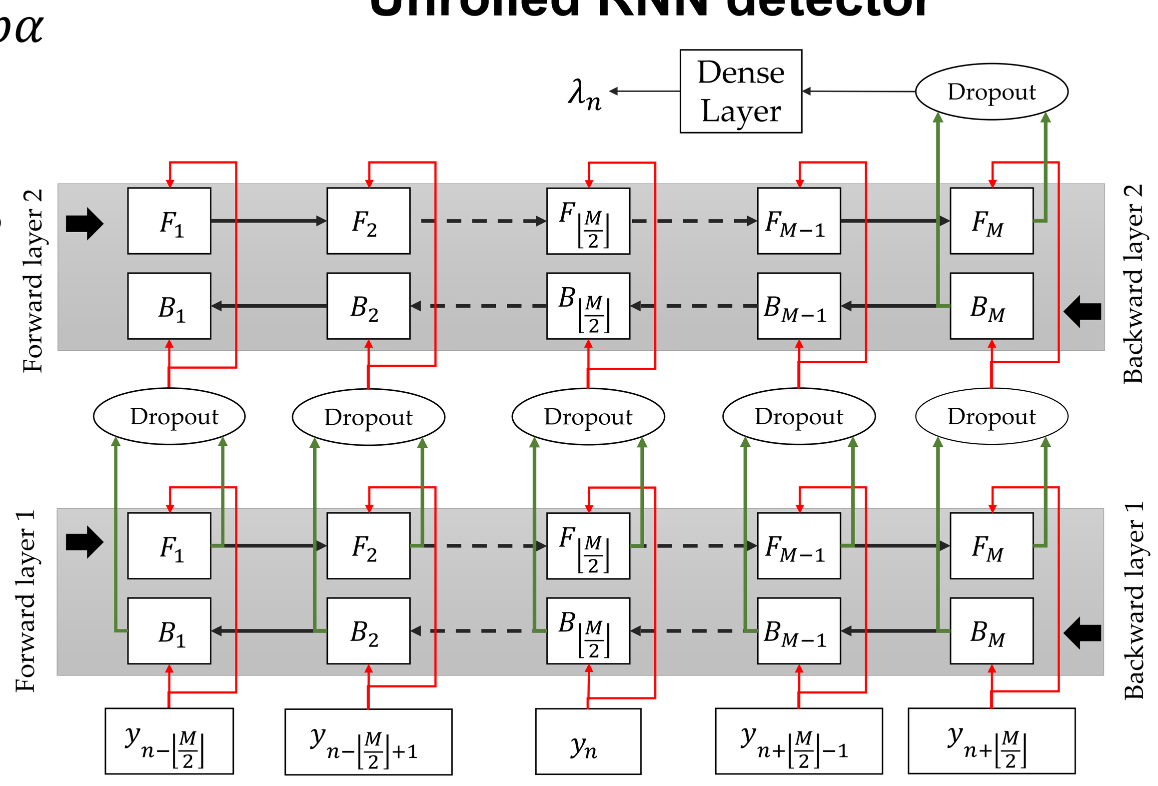
Novel contributions

- **5GNR SFN Terrestrial broadcasting** with Bidirectional Long Short-Term Memory
  - Replacement of the channel estimator, channel equalization, and LLR with one RNN
  - Superimposing pilot and data signals
    - $z = d\sqrt{1-\alpha^2} + p\alpha$

Input vector to the RNN
M consecutive OFDM symbols
Output of RNN receiver
$N \times n_{bit}$ log-likelihood ratios of bits for the following decoder

Complexity of a LSTM cell
$F = 2 \times 4 \times (I \times U + U^2 + U)$
U is number of units in a cell

Unrolled RNN detector



Adopted methodologies

- RNN System parameters and preliminary data generation for training
  - 12 OFDM carriers with 5GNR (15 kHz)
  - 4-QAM constellation and number of receiver antennas $K = 2$
  - Speed: LPLT (**160 km/h**) and HPHT (**3 km/h**)
  - 10 million pairs (y_n, c_n) at fixed **SNR= 5 dB** one for LPLT and one for HPHT
- Minimizing the binary cross entropy loss between target and response
- First RNN preliminary Hyper-Parameter optimization (α, M)
  - Fixing the number of units in RNN cell to $U = 400$ and dropout probability 0.5
- Then Full training **one for LPLT RNN** network and **one HPHT RNN** network

Reference systems

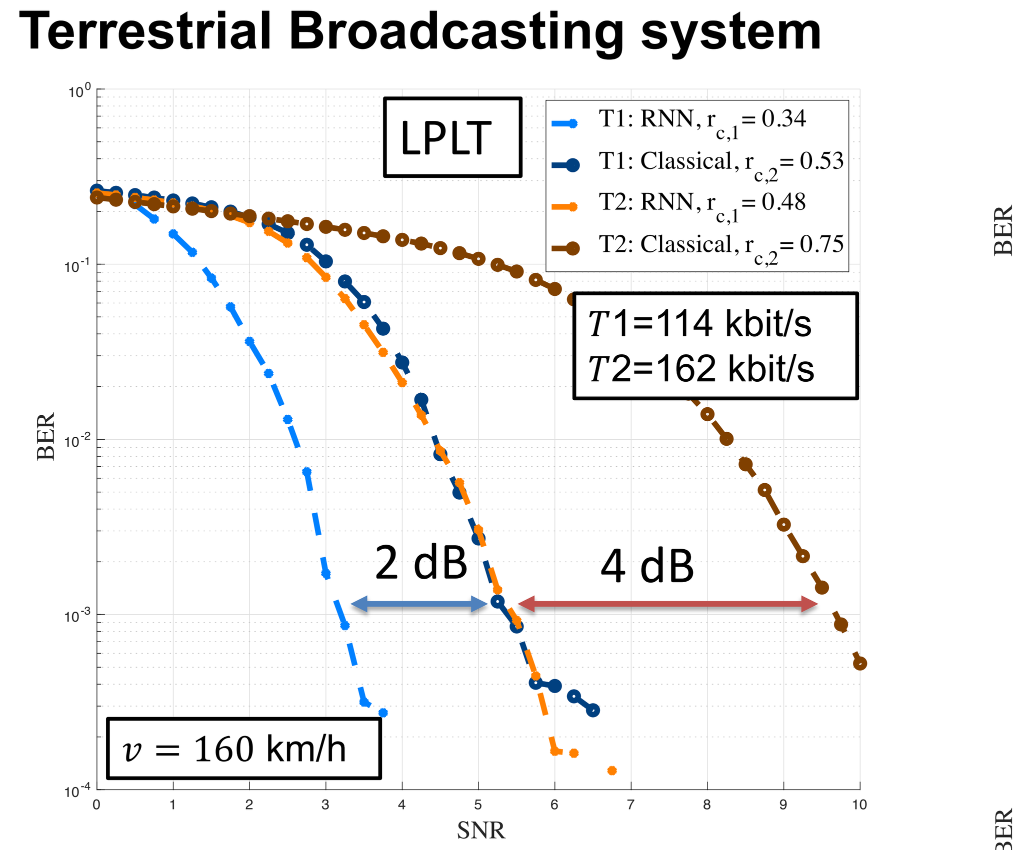
Carrier Spacing	Max ISD	Target	F_d	T_d	network	η
2.5 kHz	15 km	Mobile users	2	2	LPLT	0.6
0.37 kHz	175 km	Roof-top	3	2	HPHT	0.75

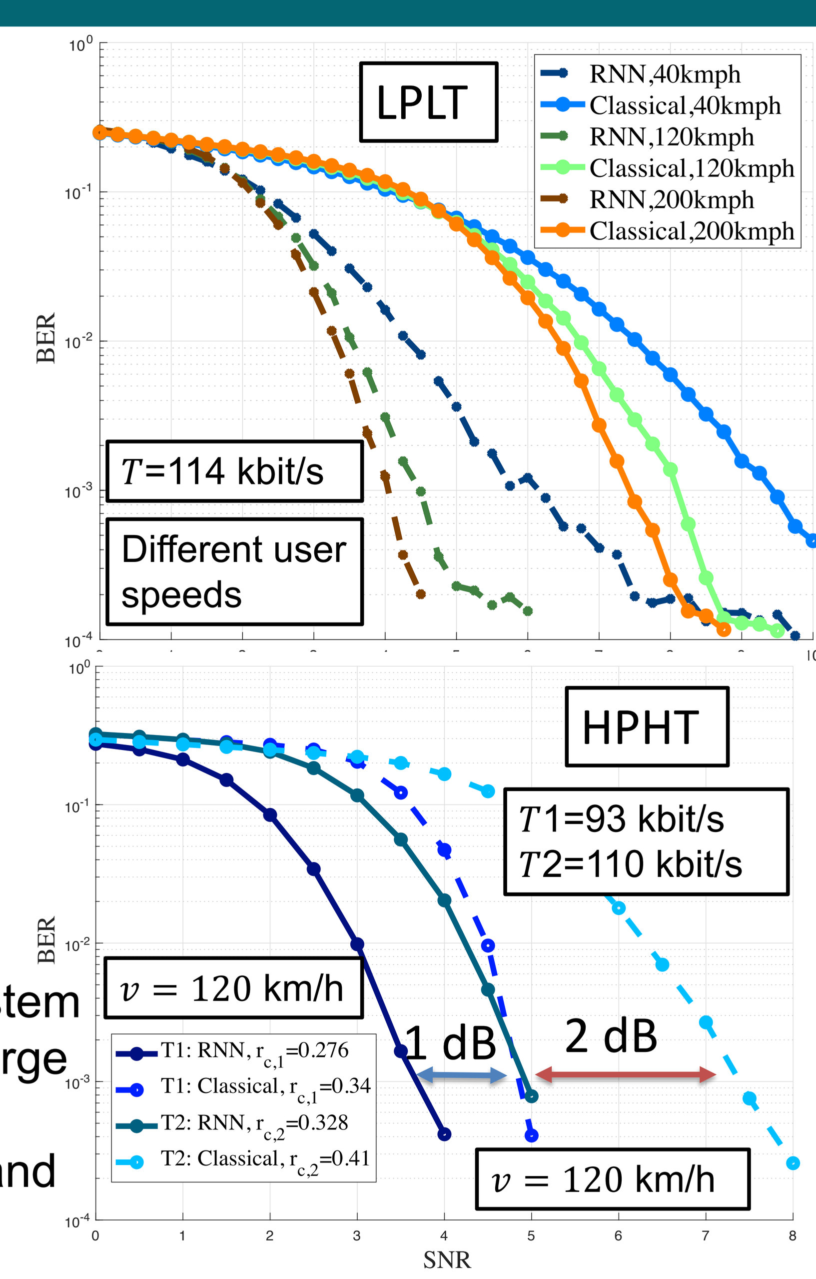
RNN Parameter optimization

LPLT	HPHT
$\alpha = 0.5$	$\alpha = 0.5$
$M = 15$	$M = 9$
$\eta = 0.9375$	$\eta = 0.9375$

Simulation results

Performances of RNN vs Classical Terrestrial Broadcasting system





- RNN largely outperforms the classical system and provides excellent performances in large ranges of SNRs and user speeds
- Flexibility to face rapid channel changes and strong ISI/ICI

Future work

- Reduction of complexity of RNN network
- Higher order modulations
- The scaling of the proposed receiver solution to the practical bandwidth
- Adoption for mobile SFN network with 5GNR numerology of other types of advanced but classical receivers
- The flexibility of a single trained RNN also to different network infrastructures ISD

List of attended classes

- 01QRRRV – Advanced iterative techniques for digital receivers (12/7/2021, 4)
- 01UJBRV – Adversarial training of neural networks (1/7/2020, 3)
- 01QTEIU – Data mining concepts and algorithms (20/1/2020, 4)
- 01UNRRV – Entrepreneurship and start-up creation (3/7/2020, 8)
- 01UJUIU – Human-Ai Interaction (9/2/2022, 4)
- 01RGBRV – Optimization methods for engineering problems (15/6/2020, 6)
- 01SFURV – Advanced scientific programming in MATLAB (29/6/2020, 4)
- 01NDLRV – Lingua italiana I livello (17/2/2022, 3)

Submitted and published works

1. Mosavat, M.; Montorsi, G. Single Frequency Network Broadcasting with 5GNR Numerology. In Proceedings of the 2021 IEEE Latin-American Conference on Communications (LATINCOM). IEEE, 2021, pp. 1–6.
2. Mosavat, M.; Montorsi, G. Single Frequency Network Terrestrial Broadcasting with 5GNR numerology using Recurrent Neural Network. Electronics 2022

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