清華大學 Tsinghua University

Time-sequence Channel Inference for Beam Alignment in Vehicular Networks

Sheng Chen, Zhiyuan Jiang, Sheng Zhou and Zhisheng Niu

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Network Integration for Ubiquitous Linkage and Broadband

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Background and Motivation

- **Background**
  - Vehicular networks [1]
    - Vehicle-to-infrastructure (V2I) communication
    - High-rate data link
    - Ultra-reliable and low-latency communications
  - MIMO systems
    - Timely and accurate CSI
  - Millimeter wave systems
    - Beam alignment [2]
  - High mobility vehicles: frequent handovers between road site units (RSUs)

[1] Gerla, Mario, and Leonard Kleinrock. "Vehicular networks and the future of the mobile internet." *Computer Networks* 55.2 (2011): 457-469.

[2] Roh, Wonil, et al. "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results." *IEEE communications magazine* 52.2 (2014): 106-113.

Related Works

- **Related works**
  - Exhaustive sweeping and hierarchical search [1]
    - Time consuming
  - Location based beamforming [2][3]
    - Rely on the positioning accuracy
  - Remote channel inference [4]
    - Infer the beam directions based on the CSI of adjacent BSs
    - Neural network based approach
    - Performance degradation caused by inference delay

[1] Alkhateeb, Ahmed, et al. "Channel estimation and hybrid precoding for millimeter wave cellular systems." *IEEE Journal of Selected Topics in Signal Processing* 8.5 (2014): 831-846.

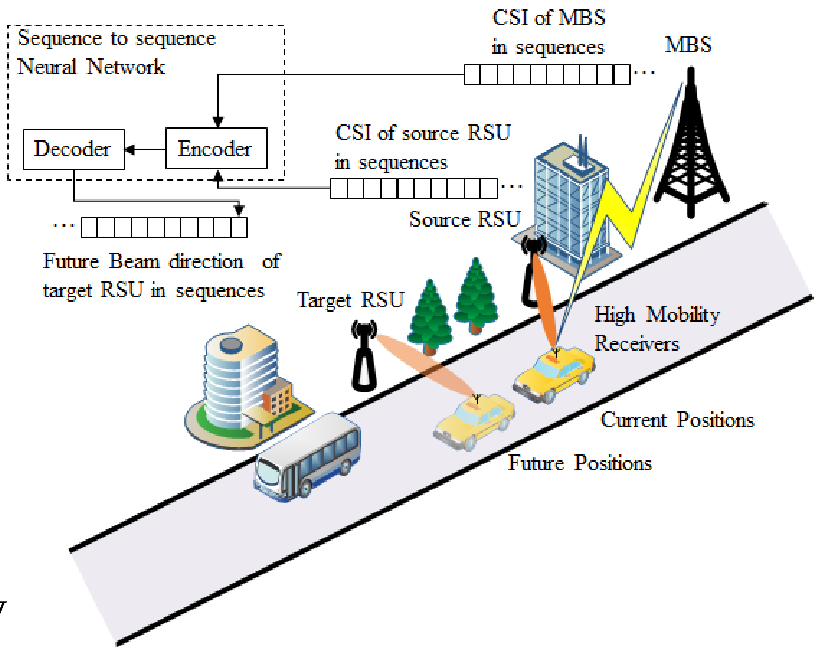
[2] Kela, Petteri, et al. "Location based beamforming in 5G ultra-dense networks." *Vehicular Technology Conference (VTC-Fall), 2016 IEEE 84th*. IEEE, 2016.

[3] Va, Vutha, et al. "Position-aided millimeter wave V2I beam alignment: A learning-to-rank approach." *Personal, Indoor, and Mobile Radio Communications (PIMRC), 2017 IEEE 28th Annual International Symposium on*. IEEE, 2017.

[4] Chen, Sheng, et al. "Remote Channel Inference for Beamforming in Ultra-Dense Hyper-Cellular Network." *GLOBECOM 2017-2017 IEEE Global Communications Conference*. IEEE, 2017.

System Model

- **System scenario**
  - V2I communication
  - Beamforming at the RSUs
  - Handover procedures between two RSUs
  - Fast beam alignment for the target RSU
  - Infer by the CSI of the source RSU or the MBS

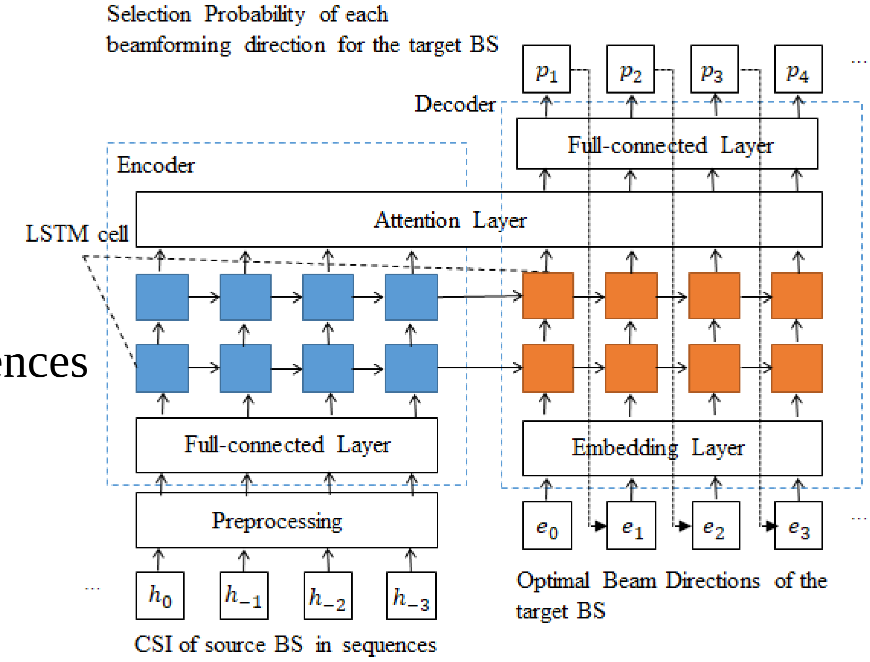


- **High-level procedures**
  - Source RSU predicts the future beam directions of the target RSU
  - Target RSU measures the inference delay
  - Target RSU establishes the link using the predicted beam directions with the measured delay

- **Target**
  - Mapping function $f([\boldsymbol{h}_{-T}, \cdots, \boldsymbol{h}_{-1}, \boldsymbol{h}_0], \boldsymbol{\theta}) = [\hat{\boldsymbol{d}}_1, \hat{\boldsymbol{d}}_2, \cdots, \hat{\boldsymbol{d}}_K]$
  - Loss function: cross entropy $$\min -\frac{1}{K}\sum_{k=1}^{K}\sum_{x=1}^{X}\boldsymbol{d}_k(x)\log\hat{\boldsymbol{d}}_k(x)$$

Network Architecture

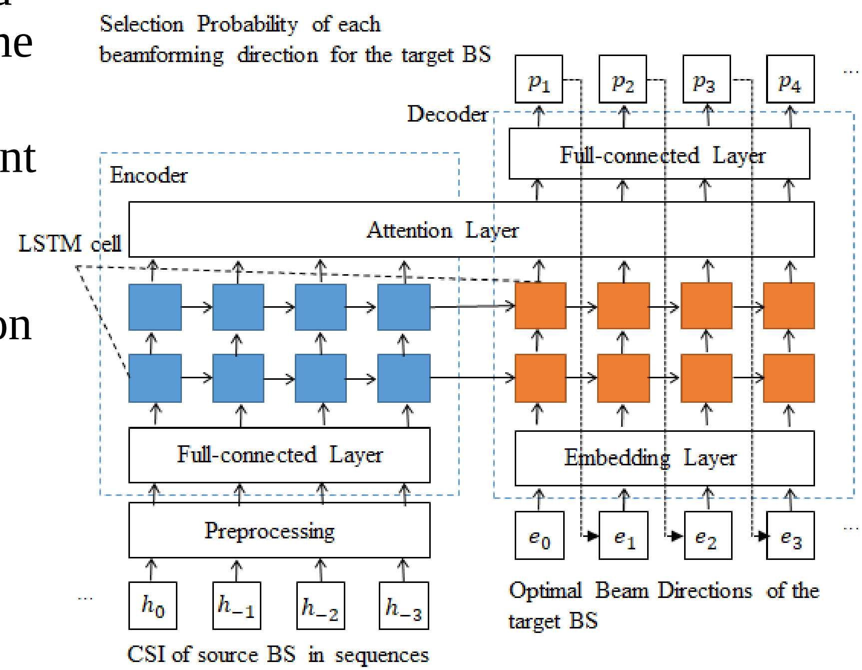
- **Sequence to sequence architecture**
- **Pre-processing**
  - Fast Fourier transformation (FFT)
  - Extract amplitude information
  - Take the logarithm
- **Encoder**
  - Input: the pre-processed channel sequences of the source BS
  - A full-connected layers
    - 256 hidden nodes, Relu
  - Two long short term memory (LSTM) layers
    - 256 hidden nodes each
  - One attention layer [1]



[1] Luong, Minh-Thang, Hieu Pham, and Christopher D. Manning. "Effective approaches to attention-based neural machine translation." *arXiv preprint arXiv:1508.04025* (2015).

Network Architecture

- **Decoder**
  - Input: target indicators of the optimal beam directions in future (training phase); based on the output of the decoder in the last time slot (inference phase)
  - Output: selection probabilities for different beam directions in future time slots
  - An embedding layer, two hidden LSTM layers (initialed from encoder), an attention layer and an output layer

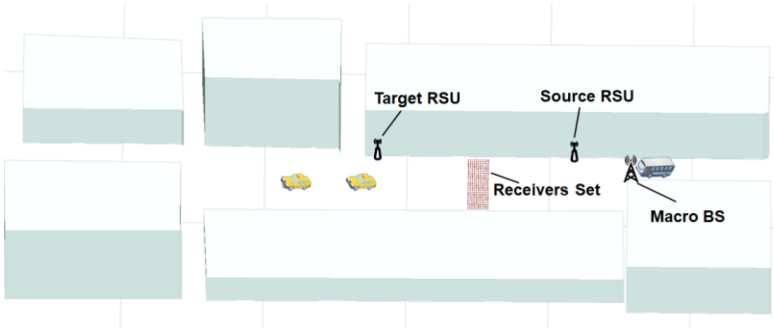


- **Loss Function**
  - Cross-entropy $\min -\frac{1}{K}\sum_{k=1}^{K}\sum_{x=1}^{X} \boldsymbol{d}_k(x)\log \hat{\boldsymbol{d}}_k(x)$

- **Data collection**
  - Channel estimations at sampling points
  - Crowdsourcing

Simulation Settings

- **Channel Model**
  - Ray-tracing based simulations
    - Obtain the AoA, AoD, complex impulse response from Wireless InSite
    - Calculate the CSI



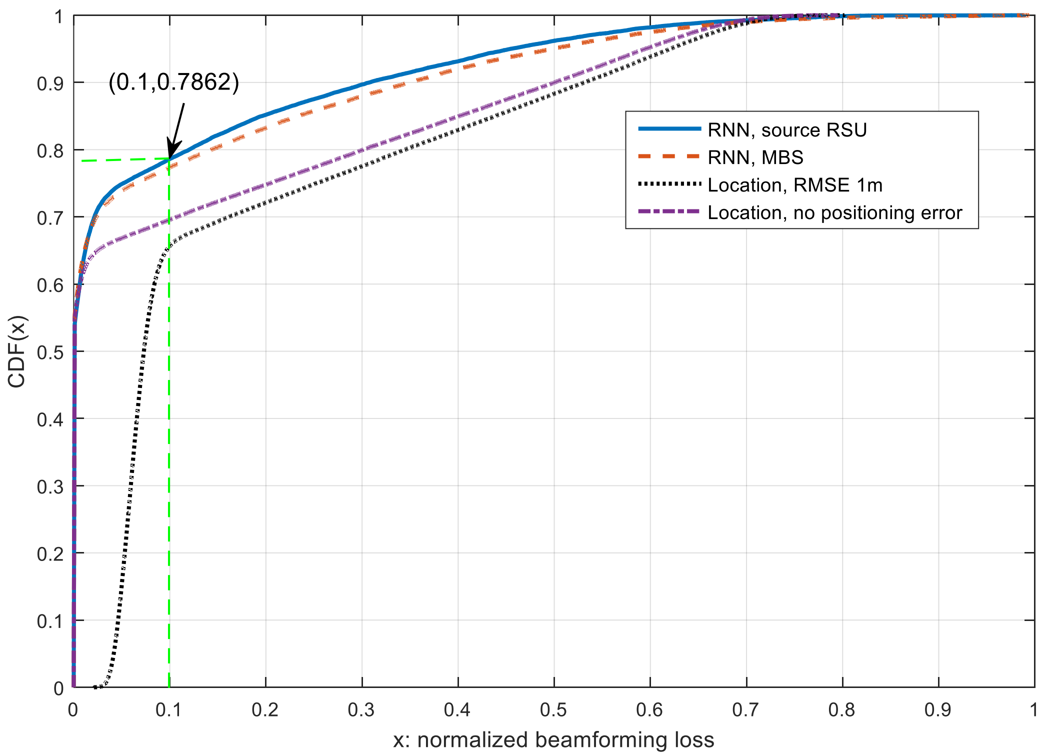
$$\mathbf{H} = \sum_{i=1}^{N_{\mathrm{P}}} \alpha_i \mathbf{a}_{\mathrm{B}}(\theta_{di}) \mathbf{a}_{\mathrm{U}}^T(\theta_{ai}),$$

  - Carrier frequency: 28 GHz
  - RSU: 1×32 linear antenna array, 3 meters high
  - MBS: 1×128 linear antenna array , 22 meters high
  - UE: single antenna, sampled in a 10×30 m grid, 0.05m spacing

- **Mobility Model**
  - Move in a line with fixed acceleration
  - Initial speed: uniformly distributed between 10 and 15 m/s
  - Acceleration: uniformly distributed between -3 m/s^2 and 3 m/s^2
  - Time interval:1 ms

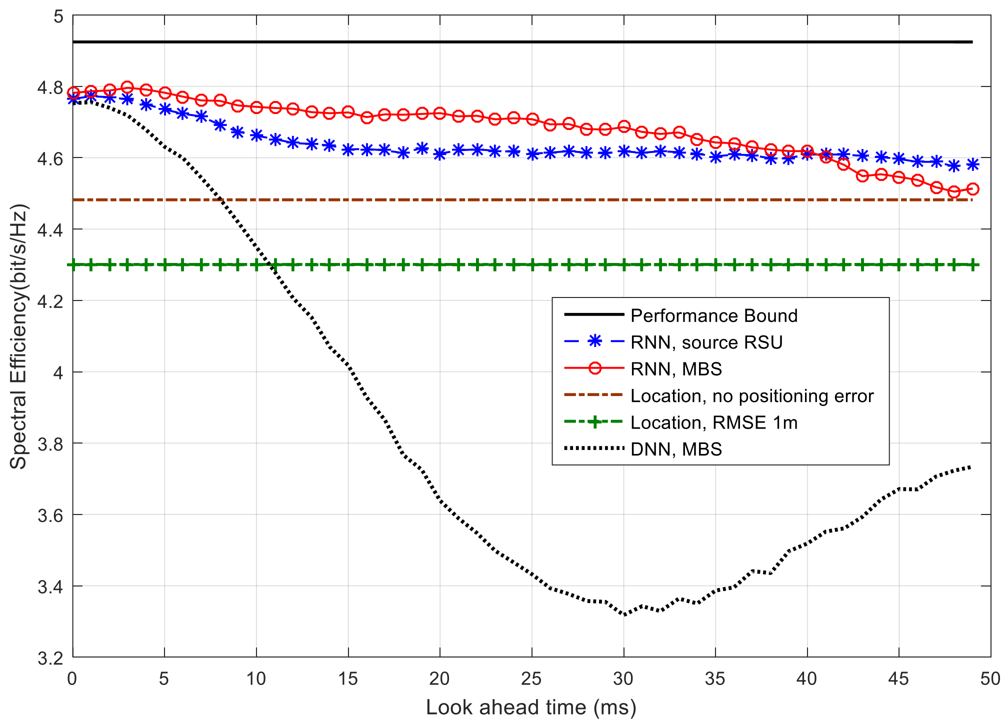
Simulation Result

- **Simulation Results on Ray-Tracing Channel Data**
  - Infer the following 50 ms based on the observations of past 50 ms
  - Performance metric: normalized distance between the received signal strength (RSS) using inferred beamformer and optimal beamformer
  - Baseline algorithm: location-based beamforming
    - Calculate the AoA and AoD of the direct path based on geometry



Simulation Result

- **Simulation Results on Ray-Tracing Channel Data**
  - Within a 4.93% performance loss compared with the optimal beamformer
  - Baseline algorithm: remote channel inference without prediction (DNN)
    - Inner product of two DFT vectors
    - Beamforming gain is not monotonically increasing with beam deviation
  - Proposed scheme can overcome the influence of the inference delay



Conclusions and Future work

- **Conclusions**
  - We propose a time-sequence beamforming inference framework with low pilot overhead for beam alignment in high mobility scenario.
  - Ray-tracing based simulations show that the proposed scheme is within a 4.93% performance loss compared with the genie-aided optimal beamformer.
  - The proposed scheme overcomes the inference delay and outperforms location-based beamforming.

- **Future Work**
  - Dynamic channel scattering environment
  - Diverse quality of service requirements

Thanks!