LSTM based Beam Tracking for mmWave Vehicular Networks

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***Abstract*—The use of millimeter wave (mmWave) frequency bands for transmission can improve data rate with the help of beamforming technology to overcome the high path and penetration losses. However for vehicle, the high mobility of vehicle results in extremely frequent beam alignment and significant overhead. In this paper, a Long Short Time Memory (LSTM) based beam tracking method was proposed for reducing overhead brought by beam alignment in mmWave Vehicular Networks, by predicting angles of beam pair at next time step through known angles of beam pairs at a certain number of consecutive time steps as features. To train this network, an time series array antenna channel data was set up by statistical channel model using time series vehicle information generated from road traffic simulation software named "Simulation of Urban MObility (SUMO)". Simulation results show that proposed LSTM based method outpreforms Kalman filter based method, and can prevent frequent beam alignment to reduce overhead while ensuring acceptable signal-to-noise ratio (SNR).**

***Index Terms*—beam tracking, mmWave vehicular networks, LSTM, Kalman filter**

I. Introduction

Unlike the channel of conventional omni-directional antennas, the channel of array antennas are directional *, which means that if higher antenna gain needs to be achieved, it is important to ensure that the beams at the receiver and transmitter are aligned with each other. Otherwise the misalignment of the beam pairs will result in serious gain reduction, degrading communications performance *. A hierarchical codebook design was proposed in * , which essentially use a dichotomous lookup to reduce overhead by using different widths of beams at different stages to perform beam search. However, this algorithm requires a high quantization level phase shifter and potentially multiple RF chains to implement, which results in high cost. In [1], Zhang et al. proposed a Kalman filter based method to

Providing reliable beam alignment for high speed vehicles is more challenging than for low speed terminals because higher speeds cause vehicles to move out of the beam coverage faster. To ensure that the vehicle is always covered by high gain beams, high frequency beam alignment is required, and it can further increase system overhead, especially when high resolution code books are used. Fortunately, due to the sparsity of mmWave channel * and the correlation between the AoA and AoD of a millimeter-wave channel and the location of the receiver and transmitter *, the channel information of a vehicle traveling along a fixed road under an LOS signal should be well predicted.

In this paper, a LSTM based beam tracking method is proposed. By using LSTM network to learn the historical channel information which was obtained from exhausted beam search, AoA and AoD of current channel between vehicle and BS can be predicted to reduce system overhead. Meanwhile, a road traffic simulation software is use to generate time seires vehicle information (e.g. position, speed, etc.) to set up time seires channel information with a statistical channel model for training the network. Compared to [1], [2], this paper differs in the following ways: 1) More realistic channel model; 2) Simultaneous prediction of AoA and AoD; 3) The outage judgment is based on the SNR of the receiver instead of the angle difference; 4) Fewer beam measurements required on average in a tracking cycle. In addition, beam search is performed more realistic than [2], by using a quantized phase shifter based beam codebook.

The following notation will be used in this paper. Matrices, vectors and scalars are denoted by bold uppercase letters (e.g. $\mathbf{A}$), bold lowercase letters (e.g. $\mathbf{a}$) and lowercase letters (e.g. a), respectively. $(\cdot)^T$ denote transpose and $(\cdot)^H$ denote conjugate transpose (Hermitian). $[\mathbf{A}]_{m,:}$, $[\mathbf{A}]_{:,n}$ and $[\mathbf{A}_{m,n}]$ denote the mth row, nth column and the mth row nth column entry of $\mathbf{A}$, respectively. $[mathbfa]_n$ denote the nth entry of $\mathbf{a}$. Beside, $\|\cdot\|_2$ denote ℓ_2-norm of a vector. $\mathbb{C}$ denote the set of complex number and $\mathbb{R}^+$ denote the set of real positive number. Complex Gaussian distribution, wrapped Gaussian distribution and exponential distribution are denoted by $\mathcal{CN}$, $\mathcal{WN}$ and $\mathcal{E}$, respectively.

II. System Model

A mmWave vehicular scenario including a vehicle with M_r antenna as receiver and a Base Station (BS) with M_t antenna as transmitter are considered. Both of them equips with uniform linear array (ULA) of half wave interval antenna as shown in Fig.1, and adopted analog beamforming used quantitative phase shifter which connect with single analog radio frequency (RF) chain. The array response vector of a uniform linear array with M half wave interval antenna is given by:

$$\mathbf{a}(M,\theta) = \frac{1}{\sqrt{M}}\left[1, e^{j\pi cos(\varphi)}, ..., e^{j\pi(M-1)cos(\varphi)}\right]^T \quad (1)$$

where φ is the arrival angle of the signal. So the array response vectors of the vehicle and BS are $\mathbf{a}_r(\phi) = \mathbf{a}(M_r, \phi)$ and $\mathbf{a}_t(\theta) = \mathbf{a}(M_t, \theta)$, respectively.

The codebook matrix of vehicle is $\mathbf{W}$, and the codebook matrix of BS is $\mathbf{F}$. Each column of the codebook matrix represents a beam pattern, each entry in the column is phase rotation for corresponding antenna element to generate directional beam. A discrete resolution $2log_2M$-bit codebook is adopted, in other words, there are $2M_r$ beam patterns for the vehicle, and M_t beam patterns for the BS.

A statistical 28 GHz mmWave channel model in [3] is used, which is modeled by real experimental data collected in New York City. The channel matrix for a L subpaths at nth time step $\mathbf{H}_n \in \mathbb{C}^{M_r \times M_t}$ can be expressed as

$$\mathbf{H}_n = \sum_{l=1}^{L} g_{ln} \mathbf{a}_r(\phi_{ln}) \mathbf{a}_t^H(\theta_{ln}) \tag{2}$$

where $g_{ln} \in \mathbb{C}$ is complex small-scale fading gain on subpath l at nth time step, $\mathbf{a}_r(\phi_{ln}) \in \mathbb{C}^{M_r}$ and $\mathbf{a}_t(\theta_{ln}) \in \mathbb{C}^{M_t}$ are array response vectors of the vehicle and BS, respectively. ϕ_{ln} is AoA of the lth subpath signal received by the vehicle at nth time step, and θ_{ln} is AoD of the lth subpath signal transmitted by the BS at nth time step. The specific parameters can be refered to [3] and will not be repeated in this paper. It should be noted that in this paper, only the case of single cluster under LOS condition is considered. In addition, the cluster angle depends on the geometric position of the vehicle and base station.

III. Beam Tracking Solution

A. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{3}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(3)", not "Eq. (3)" or "equation (3)", except at the beginning of a sentence: "Equation (3) is . . ."

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Please use "soft" (e.g., `\eqref{Eq}`) cross references instead of "hard" references (e.g., `(1)`). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

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C. Some Common Mistakes

- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
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- Do not confuse "imply" and "infer".
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- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

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The class file is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

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Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

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TABLE I
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

[a]Sample of a Table footnote.

Fig. 1. Example of a figure caption.

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ACKNOWLEDGMENT

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REFERENCES

[1] C. Zhang, D. Guo, and P. Fan, "Tracking angles of departure and arrival in a mobile millimeter wave channel," *2016 IEEE International Conference on Communications, ICC 2016*, 2016.

[2] V. Va, H. Vikalo, and R. W. Heath, "Beam tracking for mobile millimeter wave communication systems," *2016 IEEE Global Conference on Signal and Information Processing, GlobalSIP 2016 - Proceedings*, no. 1, pp. 743–747, 2017.

[3] M. R. Akdeniz, Y. Liu, M. K. Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter wave channel modeling and cellular capacity evaluation," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1164–1179, 2014.