**GRADUATION THESIS**

**Tên đề tài:** Định vị trong hệ thống 5G MIMO Millimeter wave bằng phương pháp Distributed Compressive Sensing (S-OMP)

**THESIS TITLE:** Position Estimation Through MillimeterWave MIMO in 5G Systems using Distributed Compressive Sensing (S-OMP)

**ABSTRACT**

Nowadays, large antenna arrays and millimeter wave signals are thought to be key technology for upcoming 5G networks. Their potential benefits for precise positioning are largely unexplored, despite their well-known benefits for attaining high-data rate communications. In this thesis, a 5G channel using millimeter-wave (mmWave) and massive Multiple-Input Multiple-Output (mMIMO) technologies is simulated, considering the following localization parameters: Time of Arrival (TOA), Angle of Departure (AoD), and Angle of Arrival (AoA). To achieve these precise estimations, I employ an approach built upon the Distributed Compressed Sensing—Subspace Orthogonal Matching Pursuit (DCS-SOMP) algorithm. In the presence of scatterers, we estimate the Cramér-Rao bound (CRB) on location and rotation angle estimation uncertainty from millimeter wave signals from a single transmitter. Additionally, we describe a ***novel*** two-stage algorithm for position and rotation angle estimation that attains the CRB for average to high signal-to-noise ratio. For coarse estimation, the approach is based on the multiple measurement vectors matching pursuit, followed by a refinement stage based on the space alternating generalized expectation maximization (SAGE) algorithm. Finally, we estimate accurate position and rotation angle, which is possible using signals from a single transmitter, in line-of-sight, non-line-of-sight, or obstructed-line-of-sight scenarios.

***Keywords: :*** *5G; Distributed* *compressed sensing; DCS-SOMP; parameter estimation; position estimation; mmWave; mMIMO*

**TÓM TẮT**

Ngày nay, mảng ăng-ten lớn và tín hiệu sóng milimet được cho là công nghệ chủ chốt cho mạng 5G sắp tới. Lợi ích tiềm năng của chúng đối với việc định vị chính xác phần lớn chưa được khám phá, mặc dù lợi ích nổi tiếng của chúng là đạt được truyền thông tốc độ dữ liệu cao. Trong luận án này, kênh 5G sử dụng công nghệ sóng milimet (mmWave) và đa đầu ra đa đầu ra (mMIMO) lớn được mô phỏng, xem xét các tham số nội địa hóa sau: Thời gian đến (TOA), Góc khởi hành (AoD) và Góc tới (AoA). Để đạt được những ước tính chính xác này, tôi sử dụng một phương pháp được xây dựng dựa trên thuật toán Truy tìm đối sánh trực giao trực giao không gian con (DCS-SOMP) cảm biến nén phân tán. Với sự hiện diện của các bộ tán xạ, chúng tôi ước tính giới hạn Cramér-Rao (CRB) về độ không đảm bảo ước tính vị trí và góc quay từ tín hiệu sóng milimet từ một máy phát. Ngoài ra, chúng tôi mô tả một thuật toán hai giai đoạn mới để ước tính vị trí và góc quay đạt được CRB cho tỷ lệ tín hiệu trên tạp âm từ trung bình đến cao. Đối với ước tính thô, cách tiếp cận này dựa trên việc theo đuổi nhiều vectơ đo lường phù hợp, tiếp theo là giai đoạn sàng lọc dựa trên thuật toán tối đa hóa kỳ vọng tổng quát xen kẽ không gian (SAGE). Cuối cùng, chúng tôi ước tính vị trí và góc quay chính xác, có thể thực hiện được bằng cách sử dụng tín hiệu từ một máy phát duy nhất, trong các tình huống tầm nhìn thẳng, không tầm nhìn hoặc tầm nhìn bị cản trở.

***Từ khóa:*** *5G; Distributed* *compressed sensing; DCS-SOMP; parameter estimation; position estimation; mmWave; mMIMO*

**AUTHORSHIP**

*“I hereby declare that the work contained in this thesis is of my own and has not been previously submitted for a degree or diploma at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no materials previously published or written by another person except where due reference or acknowledgement is made.”*

Signature:………………………………………………

**SUPERVISOR’S APPROVAL**

*“I hereby approve that the thesis in its current form is ready for committee examination as a requirement for the Bachelor of Electronics and Telecommunication degree at the University of Engineering and Technology.”*

Signature:………………………………………………

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**ABBREVIATIONS**

**CHAPTER 1: INTRODUCTION**

*(Tính cần thiết của đề tài, ý nghĩa khoa học và thực tiễn, đối tượng và phương pháp nghiên cứu, nội dung nghiên cứu)*

**1.1. Motivation**

In today's technological age, the application of 5G networks is growing in popularity, and having the ability to accurately estimate the location and angle of rotation of devices in 5G networks will play an important role in many areas such as intelligent transportation, object tracking and positioning, and personal communications

Mm-wave and massive multiple-input-multiple-output (MIMO) will likely be adopted in fifth generation (5G) communication networks, thanks to a number of favorable properties. Particularly, due to exploiting the carrier frequencies beyond 30 GHz and large available bandwidth, mm-wave can provide high data rate. This can be obtained through dense spatial multiplexing with large antennas. A sparse signal recovery problem exploiting the sparse nature of mm-wave channels is formulated for channel estimation based on the parametric channel model with quantized angles of departures/arrivals (AoDs/AoAs), called the angle grids. The problem is solved by the orthogonal matching pursuit (OMP) algorithm employing a redundant dictionary consisting of array response vectors with finely quantized angle grids. However, OMP (Orthogonal matching pursuit) is only used for single subcarriers, to estimate accurate position and rotation angle, S-OMP Algorithm for multiple subcarriers (Simultaneous orthogonal matching pursuit) is used. Due to the linear antenna array, the method applies to a 2D environment. Additionally, the DCS-SOMP method provides only a coarse parameter estimate, demanding further fine-tuning using the SAGE method.

**1.2. Related work**

**1.3. Contributions and thesis overview**

The contributions of this thesis are described as follows:

- This thesis presents a method for estimating position and angle of rotation accurately through mm-wave signals from a single transmitter, even in conditions of obstructions. - This method achieves the Cramér-Rao limit (CRB) for the estimation of position and angle of rotation under the signal-from-one-way-mains-correct condition from a single transmitter.

- The method proposed in the thesis uses advanced signal processing and measurement techniques such as compressed sensing and expectation maximization algorithms to achieve accurate position and angle estimation. This method is different and advanced from traditional methods. This opens up the potential of mm-wave signals and large MIMO antennas in locating and orienting devices in 5G networks.

- This thesis proposes a method for determining position and direction using mm-wave signals from a single emitter, including in conditions of obstacles.

- The results of the study show that it is possible to determine the correct position and direction using magnetic signals from a single emitter, regardless of whether or not a direct line of sight, an indirect line of sight, or an obscured line of sight.

**1.4. Thesis layout**

The remainder of this article is organized as follows:

In Chapter 2, a literature review about basic theories of 5G system including system model, basic theory of compressed sensing and methods for 5G mm-wave channel estimation is presented.

Chapter 3 presented the details of positioning problem through millimeter wave MIMO in a 5G systemincluding overview about channel estimation, OMP Algorithm, S-OMP Algorithm and positioning methods using channel information (channel estimation).

In Chapter 4, simulation results are presented and discussed.

**CHAPTER 2: BASIC THEORIES OF 5G SYSTEM**

**2.1. System Model**

We consider a MIMO system with a BS equipped with antennas and a MS equipped by antennas operating at a carrier frequency (corresponding to wavelength ) and bandwidth B. Locations of the BS and MS are denoted by and with the α ∈ [0, 2π) denoting the rotation angle of the MS’s antenna array. The value of q is assumed to be known, while p and α are unknown.

*2.1.1. Transmitter Model*

We consider the transmission of orthogonal frequency division multiplexing (OFDM) signals as in [37], where a BS with hybrid analog/digital precoder communicates with a single MS. At the BS, G signals are transmitted sequentially, where the g-th transmission comprises Mt simultaneously transmitted symbols for each subcarrier . The symbols are first precoded and then transformed to the time-domain using Npoint inverse fast Fourier transform (IFFT). A cyclic prefix (CP) of length is added before applying the radio-frequency (RF) precoding where D is the length of CP in symbols. Here, denotes the sampling period and is assumed to exceed the delay spread of the channel. The transmitted signal over subcarrier n at time g can be expressed as . The beamforming matrix is defined as where is implemented using the analog phase shifters with the entries of the form , where are given phases, and is the digital beamformer, and overall they satisfy a total power constraint . Considering the sparsity of the mm-wave channels one usually needs much less beams than antenna elements , i.e., . Also, the presence of F[n] in the proposed model leads to the extension of system model to multi-user mm-wave downlink systems with a limited feedback channel from MSs to the BS. Our work does not assume any specific beamformer. We will provide general expressions that permit the study of the impact on performance and optimization of different choices of beamformers and signals , although this is out of the scope of the paper. Our approach is also compatible with beam reference signal (initial access) procedures, and it could be complemented with a Bayesian recursive tracker with user-specific precoding.

*2.1.2. Channel Model*

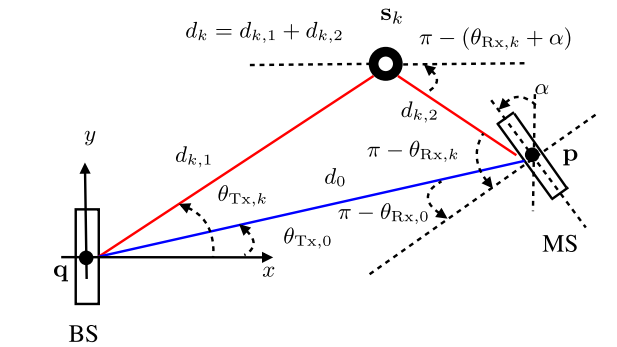


Figure 1: Two dimensional illustration of the LOS (blue link) and NLOS (red link) based positioning problem. The BS location ***q*** and BS orientation are known, but arbitrary. The location of the MS ***p***, scatterer , rotation angle ***α,*** *AOAs(, AODs(),* the channel between BS and MS, and scatterers and the distance between the antenna centers are unknown

Fig. 1 shows the position-related parameters of the channel. These parameters include , and , , denoting the AOA, AOD, and the path length (with time-of-arrival (TOA) and the speed of light ) of the k-th path (k = 0 for the LOS path and k > 0 the NLOS paths). For each NLOS path, there is a scatterer with unknown location , for which we define and

We now introduce the channel model, under a frequency-dependent array response [11], suitable for wideband communication (with fractional bandwidth up to 50%). Assuming K +1 paths and a channel that remains constant during the transmission of G symbols, the channel matrix associated with subcarrier n is expressed as

For response vectors

**,**

**,**

and

for path loss and complex channel gain , respectively, of the k-th path. For later use, we introduce and

The structure of the frequency-dependent antenna steering and response vectors and depends on the specific array structure. For the case of a uniform linear array (ULA), which will be the example studied in this paper, we recall that (the response vector is obtained similarly)

where is the signal wavelength at the n-th subcarrier and d denotes the distance between the antenna elements (we will use ). We note that when , , and (5) reverts to the standard narrow-band model.

*2.1.3. Received Signal Model*

The received signal for subcarrier n and transmission , after CP removal and fast Fourier transform (FFT), can be expressed as

where is a Gaussian noise vector with zero mean and variance per real dimension.

Our goal is now to estimate the position **p** and orientation α of the MS from . We will first derive a fundamental lower bound on the estimation uncertainty and then propose a novel practical estimator.

**2.2. Basic theory of compressed sensing**

Compressed sensing is an emerging field based on the revelation that a small collection of linear projections of a sparse signal contains enough information for reconstruction. A new framework for single-signal sensing and compression has developed recently under the rubric of Compressed Sensing (CS) [2, 3]. CS builds on the surprising revelation that a signal having a sparse representation in one basis can be recovered from a small number of projections onto a second basis that is incoherent with the first. (Roughly speaking, incoherence means that no element of one basis has a sparse representation in terms of the other basis). In fact, for an N-sample signal that is K-sparse (By K-sparse, we mean that the signal can be written as a sum of K basis functions.), roughly *cK* projections of the signal onto the incoherent basis are required to reconstruct the signal with high probability (typically c ≈ 3). This has promising implications for applications involving sparse signal acquisition. Instead of sampling a K-sparse signal N times, only cK incoherent measurements suffice, where K can be orders of magnitude less than N. Moreover, the *cK* measurements need not be manipulated in any way before being transmitted, except possibly for some quantization. Interestingly, independent and identically distributed (i.i.d.) Gaussian or Rademacher (random ±1) vectors provide a useful universal measurement basis that is incoherent with any given basis with high probability.

We briefly explain the Compressed Sensing (CS) framework proposed in [2, 3] to make the paper selfcontained.

Suppose that *x* is a signal, and let be a basis or *dictionary* of vectors. When we say that *x* is sparse, we mean that *x* is well approximated by a linear combination of a small set of vectors from . That is, where ; we say that *x* is *K-sparse* in *Ψ* and call *Ψ* the sparse basis. The CS theory states that it is possible to construct an M × N *measurement* matrix Φ, where , yet the measurements *y =* Φ*x* preserve the essential information about *x*. For example, let Φ be a *cK × N* random matrix with i.i.d. Gaussian entries, where *c = c(N, K)* is an *oversampling factor*. Using such a matrix it is possible, with high probability, to recover any signal that is *K*-sparse in the basis Ψ from its image under Φ. For signals that are not *K*-sparse but *compressible*, meaning that their coefficient magnitudes decay exponentially, there are tractable algorithms that achieve not more than a multiple of the error of the best *K*-term approximation of the signal.

Several algorithms have been proposed for recovering *x* from the measurements *y*, each requiring a slightly different constant *c*. The canonical approach [2, 3] uses linear programming to solve the minimization problem

subject to Φ*Ψθ* = *y*.

This problem requires [4] but has somewhat high computational complexity. Additional methods have been proposed involving greedy pursuit methods. Examples include Matching Pursuit (MP) and Orthogonal Matching Pursuit (OMP), which tend to require fewer computations but at the expense of slightly more measurements [5].

**2.3. Methods for 5G mm-wave channel estimation**

*2.3.1. Channel estimation using sparse CS methods*

2.3.1.1. Tối ưu chuẩn L1 (L1 trực tiếp)

2.3.1.2. Tối thiểu tổng các giá trị suy biến (L1 gián tiếp)

- FISTA

- L1-LS

*2.3.2. Sparse Bayesian Inference*

**Tổng kết chương II**

**CHAPTER 3: POSITIONING PROBLEM THROUGH MILLIMETER WAVE MIMO IN 5G SYSTEM**

**3.1. Overview about channel estimation**

**3.2. Distributed Compressive Sensing – Joint Sparsity Modles (JSM)**

*3.2.1. Theory for DCS*

In this paper, we introduce new theory and algorithms for *distributed compressed sensing* (DCS) that exploit both intra- and inter-signal correlation structures. In a typical DCS scenario, a number of sensors measure signals (of any dimension) that are each individually sparse in some basis and also correlated from sensor to sensor. Each sensor *independently* encodes its signal by projecting it onto another, incoherent basis (such as a random one) and then transmits just a few of the resulting coefficients to a collection point. Under the right conditions, a decoder at the collection point can jointly reconstruct all of the signals precisely.

The DCS theory rests on a concept that we term the *joint sparsity* of a signal ensemble. We have introduced a first model for jointly sparse signals and proposed corresponding joint reconstruction algorithms [4]. We have also derived results on the required measurement rates for signals that have sparse representations under each of the models: while the sensors operate entirely *without collaboration*, we see dramatic savings relative to the number measurements required for separate CS decoding.

In this paper, we extend our previous work by introducing a new joint sparsity model that is applicable to many real world scenarios, including sensor networks for smoothly varying signal field

*3.2.2. Joint Sparsity Modles (JSM)*

3.2.2.1. JSM-1: Sparse common component + innovations

3.2.2.2. JSM-2: Common spare supports model

*3.2.3. Reconstruction Algorithms*

3.2.3.1. Recovery via One-Step Greedy Algorithm (OSGA)

3.2.3.2. Recovery via iterative greedy pursuit

*3.3. OMP Algorithm*

OMP (Orthogonal matching pursuit) - single subcarrier

*3.4. S-OMP Algorithm*

S-OMP (Simultaneous orthogonal matching pursuit) - multiple subcarrier

* AOA, AOD => Positioning
* Advantages of S-OMP compared to OMP

*3.5. Positioning methods using channel information (channel estimation)*

Tổng kết chương III

**CHAPTER 4: SIMULATION**

4.1. Simulation Setup

4.2. Simulation Results

4.3. Discussion

Tổng kết chương IV

**CONCLUSION**

Conclusions

Future Works

**APPENDIX**

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