Efficient and Secure Spectrum Utilization for Communication & Sensing in UDN by Beamspace Processing

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***Abstract*—Motivated by a few potential use cases, this paper concerns how to further improve the utilization of the already-crowded electromagnetic spectrum for joint communication and sensing. Although tremendous efforts have been made in the last few decades towards spectrum efficiency, there is still room for improving spectrum utilization by exploiting multiple domains of the radio resources and considering synergy of multiple functions, such as communication and sensing. Detectability or sensitivity is a concerning issue especially for radio pollution monitoring and passive radar based on communication signals of opportunity. We try to improve the sensitivity without sacrificing coverage by exploiting beamspace processing. Specifically, a concept of joint transmitter-receiver (Tx-Rx) multi-beam sweeping (or hopping) based Integrated Sensing and Communication (ISAC) is proposed, taking advantage of densely deployed base stations (BSs) with beamforming capability. The Ultra-Dense Network (UDN) infrastructure with Cloud Radio Access Network (C-RAN) configuration favors centralized coordination and data processing (e.g., multi-receiver-based localization). We propose a resource partition technique to work with beam sweeping, and examine it using simulation. A passive multi-target localization framework suitable for the joint Tx-Rx multi-beam sweeping in UDN is studied, where the traditional Range-Difference (RD)-based locating technique is extended from single target to multiple targets by using a grouping algorithm. Furthermore, security issues related to narrow beam sweeping are considered from a non-cryptography perspective. We propose a location-time decoupling method and a challenge-response verification scheme against spoofing attacks in the UDN that supports beam sweeping.**

***Index Terms*—Co-existence, beamspace processing, beam sweeping (hopping), Integrated Sensing and Communication (ISAC), Ultra-Dense Network (UDN), Cloud Radio Access Network (C-RAN), passive radar, spoofing attack.**

I. Introduction

Effective spectrum utilization and coexistence is an urgent issue as the spectrum becomes more and more scarce. Many spectrally efficient schemes, such as OFDM, MIMO and underlying device-to-device (D2D) communication [1], etc., have been proposed and proved effective. Nowadays, we are not only evidencing spectrum sharing among many users in a single system, and but also entering a "system sharing" era–look at Joint Radar-Communication (JRC) [2], [3] and Integrated Sensing and Communication (ISAC) [4]. To improve the sensing performance without complicated add-ons in the existing infrastructure, a novel mechanism of sensing is urgently needed. Thanks to dense deployment of base stations (BSs) in 5G and B5G systems, in an Ultra-Dense Network (UDN) [5]–[8], multiple BSs can be used to form a large virtual array which can be viewed as a small version of the interferometry system deployed across continents for black hole imaging [9]. To accommodate fine sensing and simplify system design, we propose to employ a multi-base-station ISAC technique in a UDN with cloud Radio Access Network (C-RAN) [10] configuration for concurrent passive radar and communications in outdoor scenarios. Illustrated in Fig. 1 is a conceptual idea of target sensing in an Ultra-Dense Network (UDN), where centralized processing is valid. When a communication signal beam from a transmit BS illuminates a target, the reflected signals are received by multiple Remote Radio Units (RRUs) at BSs and down-converted to baseband IQ data, and then delivered via CPRI[1] links to the BaseBand Unit (BBU) pool for analysis.

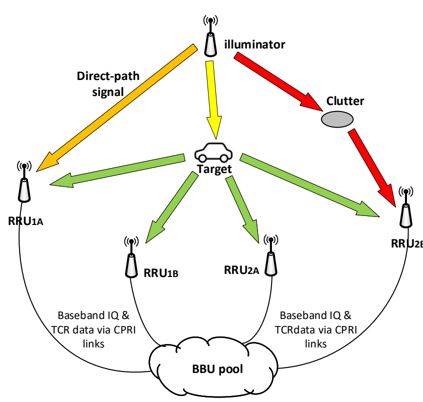


Fig. 1: Localization taking advantage of UDN with C-RAN. TCR = Transmitted Clock Reference [11].

Below are some motivating use cases that involve and are benefited from spectrum sharing.

- **Use case 1:** Traffic monitoring by using a cellular network, where the communication signal of opportunity based passive radar performs localization and tracking of vehicles. Compared to camera-based traffic monitoring, the radio-based counterpart can cover a larger area and

[1] CPRI refers to "Common Public Radio Interface (standard)."

is more robust to weather conditions. In particular, the radio-based sensing system can make use of existing cellular infrastructure and is subject to fewer installation constraints.

- **Use case 2:** Sensitive spatial-spectral radio pollution monitoring for protecting passive radio applications like radio astronomy service (RAS). Receiver beamforming and beam sweeping (or hopping) can be implemented by taking advantage of the communication facility. Especially in an UDN, multiple receivers can jointly perform spectrum sensing to achieve high-sensitivity detection.
- **Use case 3:** Synergically performing communication and sensing in emergencies. It is most important to communicate with and locate victims at the first moment when a disaster hits. At least the following three techniques can help rescue individuals: 1) multi-receiver joint beam sweeping can be used to screen an area of interest to detect weak radio signals; 2) localization-aided beamforming and beam alignment, where location information is used to refine the beamforming or accelerate millimeter wave (mmWave) beam alignment process; and 3) communication-aided localization of signal sources, where the communication system provides a rough location of the signal source at the beginning.

It has been an anticipated trend that a chunk of spectrum is shared by multiple systems, but research on efficient use of spectrum and synergic operation of different systems is still at its infancy. In this paper, we propose an ISAC system in an UDN with C-RAN configuration capable of beam sweeping.

The paper is organized as follows. In the next section, the proposed ISAC system is described. Section III introduces a way to partition radio resources in a UDN. Section IV presents a passive localization framework that extends the traditional Range-Difference (RD)-based locating techniques [12] from single target to multiple targets. Two non-cryptography security countermeasures closely related to beamspace processing are presented in section V. Some numerical results from simulation are reported in section VI, followed by conclusions along with suggested future work in section VII.

II. System Description

A. System Architecture

Consider an outdoor ISAC system possibly in a UDN with C-RAN configuration supporting centralized processing (including coordination, scheduling, and multi-receiver-based localization, etc). Such a system is conceptually shown in Fig. 2. The system supports communication as a primary function and sensing as a secondary function, where sensing should not affect normal communication. Here, sensing can be passive radar/sensing using communication signals of opportunity or localization of signal sources. Transmitters and receivers at each BS are capable of 3D beamforming and beam sweeping (steering), and DL signals sent by different BS transmitters are orthogonal to each other (this may be achieved by using frequency division, time division, etc.).

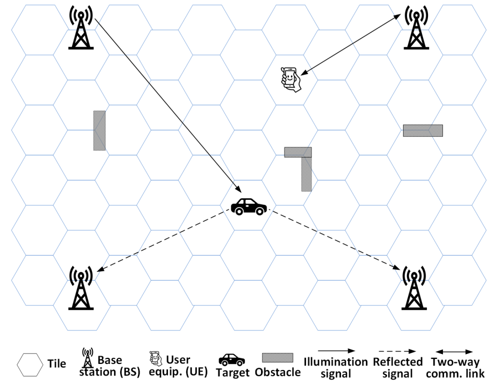
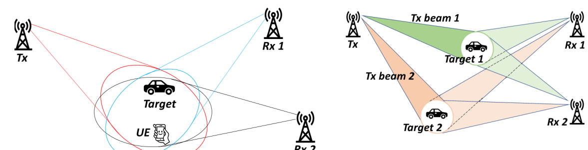


Fig. 2: A joint communication and sensing system.



(a) Joint Tx-Rx beam sweeping. (b) Joint Tx-Rx multi-beam sweeping.

Fig. 3: Illustration of beam sweeping for communication and sensing in UDN.

B. Joint Tx-Rx Multi-Beam Sweeping

According to [13], the beamforming gain is approximately inversely proportional to the beamwidth. Beamforming leads to a few benefits, such as increase of detection sensitivity and interference reduction, at the cost of reduced space coverage at a time. 2D beam sweeping has been part of 5G standards and used for initial user access [14]–[16]. It is possible to achieve joint transmitter-receiver (Tx-Rx) beam sweeping (Fig. 3a) for both communication and sensing in a UDN setup if the current protocols and processing at PHY and MAC layers can be revised. To improve communication and sensing efficiency, multi-beam sweeping can be considered, leading to joint Tx-Rx multi-beam sweeping (Fig. 3b). Precise and agile 3D beam sweeping can overcome the drawback of low power efficiency due to no beamforming and limited coverage posed by still beamforming, while achieving a high **power density** at the target or receiver. In addition, collaborative multi-receiver sweeping can be employed to form a **sensitive spatial-spectral radio pollution detector** able to estimate both location and signal strength of a radio source. Beam sweeping can have three scenarios: joint illuminator (transmitter) receiver sweeping, illuminator sweeping and receiver sweeping; in the following we use Tx-Rx sweeping, Tx-sweeping and Rx-sweeping to represent them, respectively. With beam sweeping, predefined tiles (a piece of area)[2] in an area of interest are screened by the radio beams sequentially.

III. Multi-domain Resource Sharing–Taking Advantage of 3D Beam Sweeping

Radio resources in a multi-party environment can be maximally utilized by exploiting orthogonality or quasi-

[2] Their sizes do not have to be equal and shapes do not have to be identical.

orthogonality over multiple domains. The resource orthogonality can be further exploited using different approaches, and one particularly interesting approach is to explore **beamspace**, which involves BS transmitters and receivers. Different from resource allocation (RA) that assigns radio resources to users or functions, resource partitioning organizes resources into resource groups for optimal utilization of the resources. Recall the joint communication and sensing system conceptually illustrated in Fig. 2 with communication as the primary function and sensing (passive and active) as secondary function. Transmitters and receivers at each BS are capable of 3D beamforming and beam sweeping (steering), and DL signals sent by different BS transmitters are orthogonal to each other. For analytical purpose, we assume

1) the service area of interest is divided into a large number of pixels and each pixel is represented by its center location (a tile contains a number of tiny pixels); and
2) the propagation channels are surveyed in advance, and each channel between a tile and a transmitter or receiver is classified to either line-of-sight (LOS) or blocking.

The partitioning technique introduced below for Tx-Rx sweeping can be slightly modified for applications with Tx-sweeping or Rx-sweeping. A partition is a set of n_I Tx-Rx combinations with each being associated with a different center frequency and a subset of pixels. An example of a Tx-Rx partition with two frequency bands may look like:

- Tx-Rx combination 1 with frequency band 1, expressed as a vector representative (Tx1a, Rx1a, Rx3a, Rx5a), covering one half of pixels; and
- Tx-Rx combination 2 with frequency band 2, expressed as a vector representative (Tx5b, Rx2b, Rx3b, Rx5b), covering another half of pixels;

where receivers Rx3a and Rx3b are both located at BS 3 and can work simultaneously because they use different frequency bands.

Denote by n_I, N_R, N and n_S the number of selected illuminators (radar transmitters), the number of receivers paired with an illuminator, the total number of pixels, and the size limit of any pixel cluster, respectively. A partition p can be defined by three types of sets: $\{\Omega_p^{Tx}, \Omega_{p,i}^{Rx}, \Omega_{p,i}^{pixel}, i \in \Omega_p^{Tx}\}$, where $\Omega_p^{Tx}, \Omega_{p,i}^{Rx}$, and $\Omega_{p,i}^{pixel}$ are transmitter set, receiver set and pixel set, respectively; and their set sizes are $|\Omega_p^{Tx}| = n_I, |\Omega_{p,i}^{Rx}| = N_R$, and $|\Omega_{p,i}^{pixel}| \le n_S$, respectively. For a given number of frequency bands, consider the following criterion: *100% coverage,* and *optimal detection performance.* The best partition can be obtained by using the following three steps:

Step 1: Select n_I illuminators and assign each a different center frequency;

Step 2: Form all possible Tx-Rx combinations with each containing an illuminator paired with N_R radar receivers;

Step 3: Form all feasible partitions and find out the best one.

To implement the idea we need to define some metrics. Illuminators are selected first based on some preference, and the selected illuminators must be able to cover the whole area. There can be different metrics for pairing receivers with an illuminator, associating a pixel with an illuminator, and associating a pixel with a Tx-Rx combination. In this paper, these metrics are defined based on propagation path loss. It is natural that a pixel chooses its favorite illuminator and favorite receivers by using minimum path loss as a metric. If non-coherent receivers are used for target detection, the total power received by all associated receivers can be a metric for receiver selection. Two types of scores are used in Algorithm 1 and defined below.

Algorithm 1 : Step 2 and step 3 of resource partitioning

```
Initialization:
The area of interest is divided into N pixels.
For each pixel, all its associated downlink and uplink path losses
  are provided; denoted by PL_{l,m} the path loss for a pair of source
  l and destination m.
n_I transmitters (illuminators) are selected in step 1.
N_R and n_S are given; set B = ∅.
        A. Form all possible Tx-Rx combinations:
  A1. Find out each pixel's favorite Tx-Rx combination
for n = 1 to N do
  Given pixel n, find the index of the best illuminator i =
  arg min_{i'} PL_{i',n}
  Given pixel n, find the top N_R receivers according to the
  first N_R elements in an ascend-sorted list of path losses:
  PL_{n,j_1}, PL_{n,j_2}, PL_{n,j_3}, ···
  b_n = (i, j_1, j_2, ··· , j_{N_R}), B ⇐ B ∪ b_n.
end for
  A2. Group Tx-Rx combinations (represented by b_n saved in
  B) into n_I sets C_1, C_2, ··· , C_{n_I}, where C_i contains all Tx-Rx
  combinations that are associated with illuminator i.
  B. Form all feasible partitions and find out the best one:
  B1. Form all feasible Tx-Rx partitions; each partition is a set
  of n_I Tx-Rx combinations formed by taking one member from
  each C_i, i = 1, 2, ··· , n_I.
  B2. Pixel partitioning by optimally associating
for each Tx-Rx partition do
  Optimally assign a pixel to one of n_I Tx-Rx combinations
  according to pixel-association score (1), keeping pixel cluster
  size no more than n_S;
end for
  B3. Calculate partition score using (2), and select the Tx-Rx
  partition that has the highest partition score.
Result:
The best resource partition is the selected Tx-Rx partition along
  with the associated pixel partition (pixel clusters).
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Pixel-association Score: It is an overall path **gain** considering transmitter-target and target-receiver paths. Let $PL_{l,m}$ be the path loss for a pair of source l and destination m, assuming antenna gains have been taken care of by $PL_{l,m}$; then $1/PL_{l,m}$ is the path gain which is proportional to the received power. Corresponding to illuminator i, pixel n and receiver j, the overall path gain is $1/(PL_{i,n}PL_{n,j})$, ignoring the effects of radar cross section (RCS) of a target at the pixel location, impinging angle at the target and Angle of Arrival (AOA) at the receiver. For a given partition p, the pixel-association score associated with illuminator i and pixel n is defined as:

$$\zeta_{i,n}^{(p)} = \frac{1}{PL_{i,n}} \sum_{j \in \Omega_{p,i}^{Rx}} \frac{1}{PL_{n,j}}, \; i \in \Omega_p^{Tx}, \; n \in \Omega_{p,i}^{pixel} \quad (1)$$

Partition Score: It is a summation of all path gains in a partition, reflecting the total received power, defined as:

$$\eta^{(p)} = \sum_{i\in\Omega_p^{Tx}} \sum_{n\in\Omega_{p,i}^{tile}} \zeta_{i,n}^{(p)} = \sum_{i\in\Omega_p^{Tx}} \sum_{n\in\Omega_{p,i}^{tile}} \frac{1}{PL_{i,n}} \sum_{j\in\Omega_{p,i}^{Rx}} \frac{1}{PL_{n,j}} \quad (2)$$

After this partitioning, tiles can be defined based on practical requirements and constraints that are related to beam pattern and transmit power, etc. Each tile is a group of adjacent pixels that belong to the same pixel group. Practically, a look-up table can be created to associate each tile with a departure or arrival angle, a beam pattern and a transmit power (for transmitter).

IV. Multi-target Localization Based on Range Difference Grouping

To enhance localization in a UDN setup with collaborative receivers, we propose a Range-Difference (RD) passive localization framework that extends the traditional RD-based locating techniques [12] from single target to multiple targets. The proposed work takes advantage of C-RAN structure with many cooperative BSs, and it is even promising to mitigate clutter and interference effects. The pioneering work of Smith and Abel [12] laid the foundation for succeeding work in the line of RD-based signal source locating. Given a set of ranges (or time of arrivals) between a source and sensors with known locations, the source location can be estimated using sensor fusion. However, it is not straightforward to locate multiple sources if their emitted waveforms are not distinguishable. It is the case we face that multiple targets reflect the same illuminating signal. Our approach is: for each potential target, finding out its associated set of RD measurements from all mixed RD measurements, then applying the single-target localization algorithm for each potential target.

Consider a multi-target localization setup with one illuminator, N_R receivers and M targets, and one of the receivers is designated as a reference. Each pair of reference receiver and non-reference receiver forms a baseline (thus there are $Q = \frac{N_R(N_R-1)}{2}$ baselines), and each baseline can generate RD measurements converted from time difference of arrival (TDOA) measurements. Let receiver j be the reference, denote the RDs at the remaining receivers by $d_{i,n}; i = 1,2,3,\cdots,M; n = 1,2,3,\cdots,N_R; n \neq j$; and let $\mathcal{RD}_i = \{d_{i,n}; n = 1,2,3,\cdots,N_R; n \neq j\}$ be the RD set for target i. According to [12], given a set of RD measurements, i.e., a composition of Q RD measurements from the Q participating baselines, a location estimate along with an equation error $\tilde{\epsilon}$ in close-form can be obtained. This early work inspires a RD identification method formulated as an optimization problem for target i:

$$\mathcal{RD}_i = \underset{\widehat{\mathcal{RD}}_i}{\arg\min}\, J(\widehat{\mathcal{RD}}_i) \quad \text{subject to constraints} \quad (3)$$

where $J = \tilde{\epsilon}^T \tilde{\epsilon}$ is the equation-error energy defined in equation (12) in [12], and used here as a fitness indicator in our scheme; the constraints can be defined based on location related information such as AOA and/or target area boundaries determined by the predefined tiles. In practice, $\widehat{J}$, the estimate of J, can be calculated using the J equation with R_s being replaced by $\tilde{R}_s$ (given by equation (13) in [12]). Furthermore, a weighting matrix W may be applied: $\widehat{J} = \tilde{\epsilon}^T W \tilde{\epsilon}$. Of course, solving (3) directly is very difficult. Instead, we propose to use a RD grouping algorithm to find out a proper RD set for each potential target. Shown in Algorithm 2 is the pseudo code for such an algorithm. The algorithm needs to know the number of targets in prior, and there are different ways to estimate it. This issue is out of the scope of this paper, and in our testing we assume there is no more than one target in a tile.

Algorithm 2 Range difference grouping

Initialization:
Define equation-error energy estimate $\widehat{J} = \tilde{\epsilon}^T W \tilde{\epsilon}$ according to equations (12) and (13) in [12]
Give an energy threshold T_{energy} and a discount factor γ
Get M, number of estimated number of targets
Input constraints, such as rough target location boundaries determined by predefined tiles.
Number the N_R participating receivers with $1,2,3,\cdots,N_R$
Assign receiver j ($1 \leq j \leq N_R$) as a reference (required by the RD-based technique [12])
Form M initial range difference sets $\mathcal{RD}_i = \{d_{i,n}; n = 1,2,3,\cdots,N_R; n \neq j\}$, $i = 1,2,3,\cdots,M$
grouping:
for i=1 to M **do**
    $v_0 = \widehat{J}(\mathcal{RD}_i)$
    $v_{min} = 0$
    while $v_0 - v_{min} > T_{energy}$ & not timeout **do**
        for k=1 to M & $k \neq i$ **do**
            $\widetilde{\mathcal{RD}}_k = \mathcal{RD}_k, d_{i,n} = d_{k,n}, n = 1,2,3,\cdots N_R, n \neq j$
            $v(k) = \widehat{J}(\widetilde{\mathcal{RD}}_k)$
        end for
        $v_{min} = min(v(k))$, $k' = argmin_k(v(k))$
        if $v_0 - v_{min} > T_{energy}$ & constraints are met **then**
            Set $d_{i,n} = d_{k',n}$ in $\mathcal{RD}_i$
        end if
        $T_{energy} \Leftarrow \gamma \cdot T_{energy}$
    end while
end for
Output:
Refined RD measurement sets $\mathcal{RD}_i, i = 1,2,3,\cdots,M$

V. Secure Utilization of Spectrum

A. Random Sweeping for Location-Time Decoupling:

The advantages of beam sweeping have been mentioned above, but the tile screening has to follow a predefined tile-time pattern. In other words, location and time are coupled, which can lead to an information leaking problem. For instance, if an illuminator screens an area by following a tile-time pattern known to a passive attacker (malicious receiver), then the attacker can know from which tile a received signal bounces within a specific time slot. On the other hand, in the radio pollution monitoring scenario, the tile-time pattern cannot be leaked to a potential rule violator. One solution to these issues is to randomize the tile-time pattern, virtually achieving location-time decoupling.

B. Detect and Locate Spoofers via Location-Time Challenge-Response Verification

Detecting Spoofers: Most existing techniques for spoofer detection exploit the spoofers' location fingerprinting [17], [18]. For instance, for each UE (radio source), N_R collaborative receivers can form a unique location-based identity which is a vector $\boldsymbol{r} = (r_1, r_2, r_3, \cdots, r_{N_R})^T$ based on N_R RSS recordings. With UE location information collected and updated during system operation, the system authority can detect (at some probability) an abnormal location based on some sort of distance metric. Besides the RSS, AOA and TDOA measurements have been used as well against spoofing attacks [17]. When a spoofer is closed to a legitimate UE, most existing spoofing detection schemes do not work well.

Locating Spoofers: In principle, many existing localization techniques can be used to locate a spoofer, provided the spoofer emit signals. However, locating a spoofer is harder than detecting it, because the spoofe's signals are mixed with other signals and cannot be recognized and extracted out accurately.

The drawbacks and limitations of traditional location-based anti-spoofing methods are mainly due to poor location resolution. Aimed at improving spoofing detection performance, we propose a PHY-layer-based challenge-response verification by leveraging beamspace processing in a UDN with C-RAN configuration. Consider an ISAC system with the following setup: L predefined tiles, n_I BS transmitters capable of beamforming, N_R BS receivers capable of beamforming, and UEs and spoofers (both with downlink and uplink communication capability). Tx-sweeping and Rx-sweeping will be employed in our scheme described in the following.

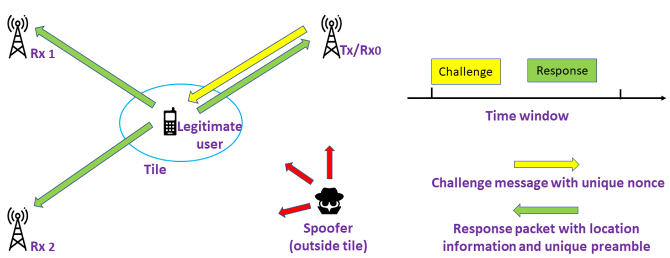

Fig. 4: Location-time challenge-response verification.

Location-Time Challenge-Response Verification and Spoofer Localization (Fig. 4): Its procedure (protocol) is as follows. For each tile, 1) the system transmits a challenge message with a **nonce** (one-time-use random number) via a selected BS transmitter whose radio beam pointing at the tile; 2) if a legitimate UE is in the tile and receives the challenge message, the UE is supposed to send back within a given time window a response packet containing i) a preamble generated using the nonce and ii) a message with current location information; 3) if the system receives the response packet via N_R BS receivers whose radio beams pointing at the tile, the received message is analyzed, and 4) the N_R preamble copies of the response packet, if received, are used to locate the signal source (the preamble is known to the system). The above process is performed for each tile by following a sequence (tile-time pattern) known only by the system authority.

This method contains two mechanisms against spoofing attack: a) the nonce (thus the corresponding preamble) is associated with both location (tile) and time window, which reduces the chance that a spoofer sends back a correct response packet; and b) improved localization accuracy, thanks to dense deployment of BSs and capability of fine-grained agile beam sweeping.

VI. Numerical Results

In this section, we provide numerical results to demonstrate the proposed resource partitioning and multi-target localization schemes.

A. Resource Partitioning

Shown in Fig. 5 is a system layout in a 600 m $\times$ 600 m area with five BSs; three frequency bands around 6 GHz are considered, and the following parameters are used in simulation: $n_I = 3$, $N_R = 3$, $N = 800$, $n_S = 67$.

To help select illuminators, an illumination coverage score can be defined by counting the number of tiles whose received powers from an illuminator are above a given threshold. Equivalently, the received power threshold can be replaced by path loss, and such a score is shown in Fig. 6. One can see that if we need to have three illuminators, transmitters 1, 3 and 5 should be selected.

Finally, by performing Algorithm 1, we are able to find the best partition with three Tx-Rx combinations along with

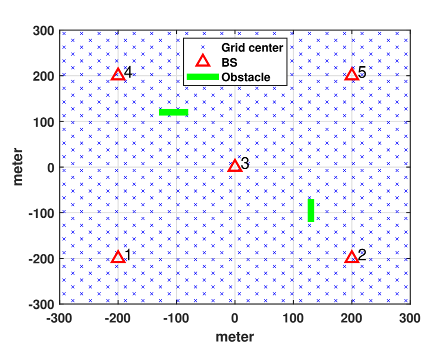

Fig. 5: System layout with $N = 800$ pixels.

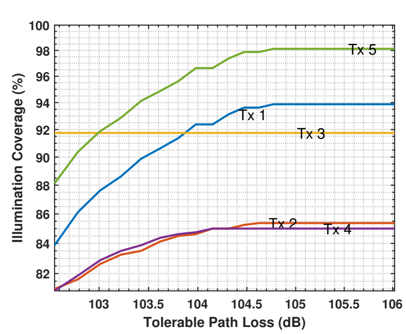

Fig. 6: Illumination coverage score vs. tolerable path loss.

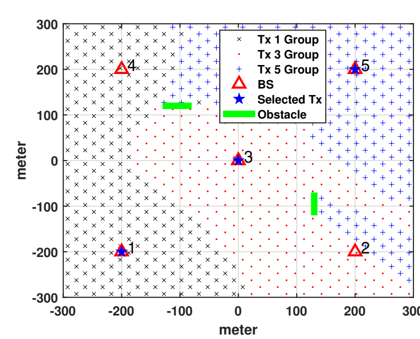

Fig. 7: Optimal partition with three Tx-Rx combinations along with three tile groups.

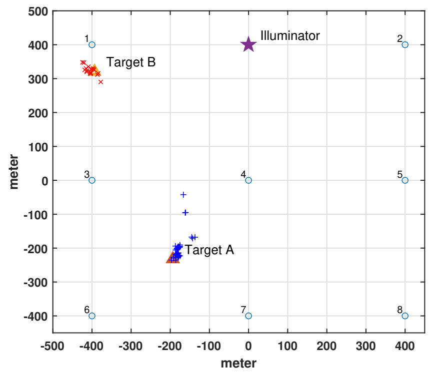

Fig. 8: Passive localization of two targets ("+" and "x" represent location estimates of targets A and B, respectively).

three tile groups (see Fig. 7). These Tx-Rx combinations are: (Tx1a, Rx1a, Rx3a, Rx4a), (Tx3b, Rx1b, Rx2b, Rx3b), and (Tx5c, Rx2c, Rx3c, Rx5c).

B. RD-Based Multi-target Localization

After the RD grouping process, the traditional RD-based single-target localization method can be applied for each target. Preliminary evaluation result is depicted in Fig. 8, where one illuminator and eight receivers work together to locate two passive targets, and the weighting matrix is an identity matrix (no weighting). RD grouping is not perfect, which can lead to estimation outliers. However, most of such outliers are obviously wrong and can be eliminated based on beam coverage associated with predefined tiles. It is also observed from the simulation that timing offsets at nanosecond level almost have no impact on location estimation.

VII. Conclusions

We have proposed a concept of joint Tx-Rx multi-beam sweeping based communication and sensing that takes advantage of UDN infrastructure with C-RAN configuration capable of 3D beamforming, in order to improve power efficiency and detection sensitivity. Coarse mmWave beam sweeping has been part of the 5G standards; thus, it is likely that fine-grained agile beam sweeping can be anticipated to appear in a few years. To support this concept, the multi-domain resources need to be partitioned and then assigned. A resource partition technique has been provided in detail and demonstrated using simulation. Of course, the partitioning technique can be extended to deal with more sophisticated scenarios by taking into account various factors, such as, hot spots that need more attention, variable transmit powers and/or antenna gains for different tiles, transmit power, tile dwell time, RCS, incident and departure angles, etc. To enhance localization in a UDN setup, a RD measurement grouping technique is proposed to extend the traditional RD-based locating technique from single target to multi-target, without resorting to other means like precise AOA estimation. Our preliminary result suggests that the grouping algorithm does work. It is also promising to extend our current work to handle interference and clutters. Additionally, we have proposed non-cryptography methods to handle security issues uniquely related to beam sweeping. The verification scheme is supposed to be time and location sensitive. In the future, these security countermeasures need to be further tested, with focus on identifying closely-located legitimate users and spoofers.

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