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FACULTY OF ENGINEERING – SOHAG UNIVERSITY

Sohag Engineering Journal (SEJ), VOL. 1, NO. 1, MARCH 2021

EFFICIENT mmWAVE BEAM TRACKING FOR 5G AND BEYOND WIRELESS SYSTEMS

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Abstract

Recently, 60 GHz wireless networks have drawn much attention due to availability of huge bandwidth around 60 GHz frequency band which has ability to support very high data rate, i.e., up to 6.7 Gbps. This is also called millimetre wave (mmWave) networking which paves the way for realization of Gigabit WLANs. However, heavy attenuation at 60 GHz frequency band limits the range of transmitted signal up to few meters. In order to extend the range of 60 GHz signal, use of directional antennas have been suggested as the most viable solution. Directional antennas use array of antennas to beamform in a particular direction. The difficulty arises when a user is moving. It is a challenging task to track the movement of a user and thus direct the beam in intended direction. According to the IEEE802.11 ad standard, each deployed mmWave AP in the target environment performs an exhaustive beam forming training (BT) to track the moving user to maintain the link. In this paper, we propose a mmWave user tracking scheme in outdoor environment based on the previous user equipment (UE) context information's. Where, the preceding beam ID directions used to predict a group of mmWave Tx beams to search on them to find out the best beam ID for the next UE location. Simulations show that the proposed scheme highly reduces BT complexity comparable to conventional scheme with conversing almost same performance.

 DOI: 10.21608/SEJ.2021.155712.

Keywords: 5G, MmWave, Beamforming training (BT) Exhaustive BT, Initial access, Geometry aware, Mobility.

1. INTRODUCTION

The worldwide rapid adoption of high-end devices such as mobile tablet, wearable devices and smartphones exacerbates the demand for high data rate services [1]. Fifth generation (5G) mobile cellular networks have been introduced to face the bottleneck of the conventional mobile networks in addressing the explosive growing demand for high data rate mobile applications [2]. Recently, 60 GHz wireless networks have drawn much attention due to availability of huge bandwidth around 60 GHz frequency band which has ability to support very high data rate (i.e., up to 6.7 Gbps). This is also called millimetre wave (mmWave) networking which paves the way for realization of Giga bit WLAN. Supported application could be uncompressed video streaming, video games and projection to wireless displays. However, heavy attenuation at 60 GHz frequency band limits the range of transmitted signal up to few meters. Also, presence of obstacles, i.e., walls, furniture, human body shadowing completely blocks the 60 GHz electromagnetic wave. In order to extend the range of 60 GHz signal, use of directional antennas have been suggested as the most viable solution. Directional antennas use array of antennas to beamform in a particular direction. The difficulty arises when a user is moving. It is a challenging task to track the movement of a user and thus direct the beam in intended direction. To overcome these losses highly

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directional antennas are employed to concentrate the signal power towards a specific direction and provides sufficient link margin. IEEE 802.11ad [3] mmWave WLAN standard was developed for communications in the 60 GHz band, where an exhaustive search medium access control (MAC) based beamforming training (BT) protocol is used for mmWave link establishment. Nevertheless, this exhaustive search BT complicates the mmWave link establishment process, where the user equipment (UE) and the deployed mmWave access points (APs) should jointly sweep the wide angular space to select the best transmission and reception communication beam configuration. This time consuming and high overhead BT will highly degrade the performance in terms of total system throughput and latency time. In addition, transmission in narrow beams results in discontinuous availability of mmWave access in the space, which makes the mmWave links fragile with low quality.

The consequences become more serious in the case of dynamic environments (i.e., moving users), where a permanent and intensive BT should be performed to track the direction of UE in respect to the deployed mmWave APs to maintain the communication link during the connection time. As a result, the time-consuming exhaustive search BT makes it difficult to establish and maintain a mmWave link and support mobility robustness. Consequently, it will be difficult to meet the ultra-low latency requirement needed for the future 5G mobile networks. Also, numerous BT schemes have been introduced, to enhance the conventional exhaustive search BT, based on user context information [4-6]. Where authors used UE location to estimate a group of best mmWave Tx beams in which UE has the most probability to be in. Other techniques utilize the sparse nature of the mmWave channel to estimate the mmWave channel matrix between AP and UE is used in [7] to improve the mmWave BT, hence assisting in enhancing user tracking process. In these works, it is essential to estimate channels for all transmitter (TX) and receiver (RX) antenna pairs, which requires high computational complexity due to great number of used antenna elements. Authors in [8] proposed a beam tracking solution based on the estimation of angles of arrival and angles of departure (AoAs/AoDs), where the sparsity of the channel is used to reduce the estimation complexity. However, their solution based on the assumption that the AoAs/AoDs deviation due to mobility is small, which is not accurate assumption in actual mobility scenarios. Although, the above schemes highly reduce BT complexity and setup time. Their authors omitted studying the impact of the BT overhead and latency on the system performance of realistic mmWave networks with mobility.

In this paper, we propose an efficient mmWave BT scheme for communications in outdoor environment with UE mobility. The proposed scheme based on leveraging the current beams ID directions to reduce the search space to find the best beams IDs for the next UE location, so the BT process needed for link establishment will highly relaxed. Moreover, leveraging the previous UE’s beam IDs enables the network to efficiently track the location of a moving UE and maintain the communication direction for the next UE location. Simulation results show that a significant BT complexity reduction can be achieved with the proposed scheme in addition to converse almost same mmWave received power, which greatly enhances the system performance in terms of the average throughput of a moving UE compared to the conventional exhaustive search BT. Also, simulations demonstrate that the proposed scheme extremely the complexity for mmWave link establishment and beam tracking than the conventional system.

The reminder of this paper is organized as follows; Section 2 presents the system model. Section 3 provides the conventional IEEE 802.11ad and the proposed schemes. The performance of the proposed scheme is evaluated in Section 4 using numerical simulations. Finally, conclusion is presented in Section 5.

2. SYSTEM MODEL

2.1. System Architecture

Fig. 1 shows the details of the system architecture. In this architecture, multiple 60 GHz mmWave APs are deployed in an outdoor target area e.g., campus, open markets, etc. The deployed APs are connected to an ALC via high-speed links i.e. Fiber cables to form a WLAN and X2 interfaces. The ALC provides the processing and controlling of the connected group of APs. Also. ALC acts as an external gateway connects the WLAN to cellular system and Internet. Also, all the geometric information of the target area including the coordinates of the APs locations are exist in the ALC.

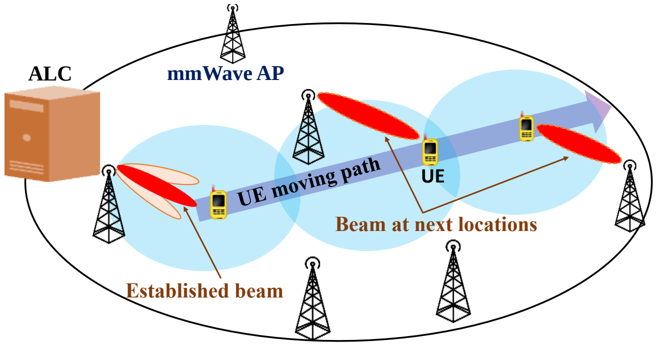

Fig. 1. The mmWave system architecture.

2.2. MmWave Propagaion Link Model

The propagation model for outdoor urban environment defined in [9] is considered for mmWave communications, which expressed as follows:

$$PL(d)_{dB} = PL(d_0)_{dB} + 10n\, log_{10}\left(\frac{d}{d_0}\right) + \mathcal{X}\sigma \tag{1}$$

where, $PL(d)$ means the path loss and the shadowing value at distance d from a mmWave SC. d_0 represents the reference distance, which is set as 5 m. $PL(d_0)$ is the path loss at d_0 and is equal to 82.02 dB for the 60 GHz band. $\mathcal{X}\sigma$ is the shadowing term in dB, which is a zero mean random variable with standard deviation, σ. n is the exponent path loss. The antenna gain $G_{dB}(\Phi,\Theta)$ in a certain azimuth and elevation angles Φ and Θ, respectively, can mathematically formulated as follows [10]:

$$G_{dB}(\Phi,\Theta) = G_m(dB) - 12\left(\frac{\Phi-\Phi_0}{\Phi_{-3dB}}\right)^2 - 12\left(\frac{\Theta-\Theta_0}{\Theta_{-3dB}}\right)^2 \tag{2}$$

$$G_m(dB) = \left(\frac{16\Pi}{6.76\Phi_{-3dB}\Theta_{-3dB}}\right), \tag{3}$$

where G_m denotes the maximum beam gain, and Φ_{-3dB} and Θ_{-3dB} are the azimuth and elevation half power beamwidths, respectively, and Φ_0 and Θ_0 represent the azimuth and tilt angles of the beam center, respectively. Accordingly, the received power by a UE at a distance d from an mmWave SC, $P_r(d)$, is expressed as:

$$P_r(d)_{dB} = P_t(dBm) + G_{dB}(\Phi,\Theta) - PL(d)_{dB}, \tag{4}$$

where, P_t is the mmWave AP TX power. $PL(d)_{dB}$ and $G_{dB}(\Phi,\Theta)$ are calculated from (1) and (3), respectively.

Clearly, from Eq. (4) that the maximum received power by a UE located at distance d, $P_{rmax}(d)$, is achieved with the maximum value of the antenna gain G_{mdB}. Therefore, the mmWave AP transmission range, $\Re_t$, which is the maximum distance from the AP where the received power exceeds the power threshold P_{th}, can be calculated as follows:

$$\Re_t = max\{d|P_{rmax}(d) \geq P_{th}\} \tag{5}$$

Generally, P_{th} depends on the receiver sensitivity and in this paper, is selected to be the power level essential for modulation coding scheme (MCS) zero as defined by IEEE 802.11ad standard. So, the coverage area, $\Omega_{cov}^{(i)}$, of an mm-Wave APi located at $(x_{AP}^{(i)}, y_{AP}^{(i)}, z_{AP}^{(i)})$ can be specified by a circular disc in the UD's horizontal plane and centred at $x_{AP}^{(i)}$ and $y_{AP}^{(i)}$ in the x and y axes, respectively. The radius, $\Re_{\text{cov}}$, of the horizontal coverage area is a function of $\Re_t$. Fig.3 shows the 3D beam configuration for a mmWave AP, as shown in Fig. 2. In this paper, the fixed beam configuration strategy is adopted, since group of beams with fixed direction are configured for each deployed mmWave to span its coverage area.

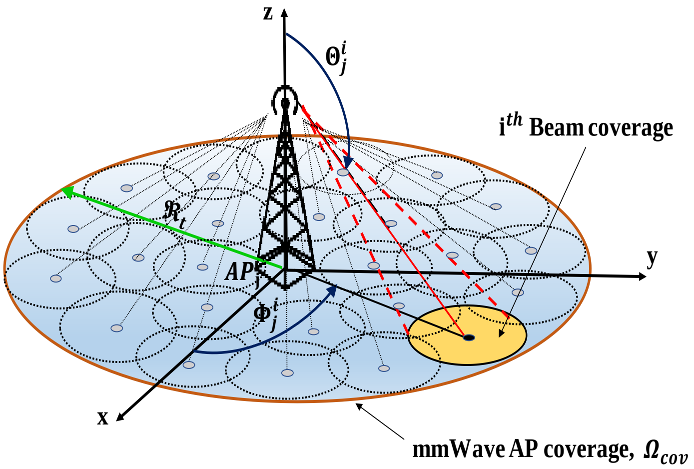

Fig. 2. 3D beam configuration for mmWave AP.

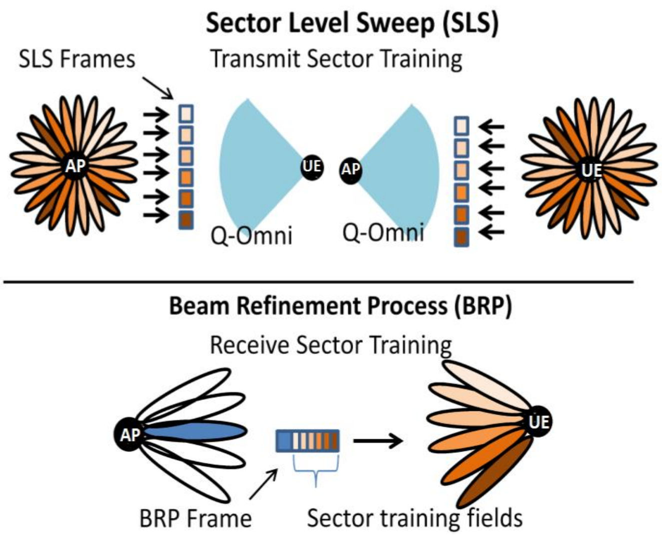

Fig. 3. IEEE 802.11ad BT protocol.

3. MMWAVE BEAM TRACKING

3.1. Conventional IEEE 802.11 ad Exhaustive Scheme

In IEEE 802.11ad, the BT consists of two stages: sector level sweep (SLS) phase, and beam refinement process (BRP) as illustrated in Fig. 3. The SLS phase allows the communication at a low physical (PHY) rate for enabling both the AP and the UE to determine the best coarse-gain TX sectors. In this phase, the AP transmits a training frames on each sector in all directions, while the UE keeps receiving in quasi-omni mode to determine the best TX sector for the AP. Similarly, the UE sends a training frame per each sector, while the AP keeps receiving in quasi-omni mode to find out the best TX sector for the UE. Finally, the information of the best TX sectors are exchanged between the AP and the UE. The SLS is a very time-consuming and a high overhead process, where a huge number of training frames should be transmitted to cover all the angular space between the AP and the UE. In the BRP phase, the sectors found in the SLS phase, using quasi-omni mode, are fine-tuned to enable link establishment between the AP and the UE with the highest data rate. Unlike the SLS phase, the BRP phase adds less overhead to the BT process. Obviously, the link establishment in the IEEE 802.11ad is a time-consuming and a high overhead process. Besides, the standard handles the link quality degradation due to UE mobility via beam refinement procedure searching around the present TX/RX beam pairs for maintaining the link. However, in high UE mobility, this procedure may be unable to perform an efficient link maintaining, and a link re-establishment using the exhaustive search BT via all deployed APs should be performed to re-establish the link with the UE. Which in turns highly reduces the overall system performance.

3.2. Proposed 3D Beam Tracking Scheme

As discussed previously, mmWave link establishment and turns to be a challenging issue to enable robust mmWave network realization due to the special nature for these bands and its dependency on high directive transmission procedures. The problem become more serious with UE mobility, since the network should track the beam to preserve the link with the UE. In the proposed scheme, in the case of quality degradation of link between a UE and a mmWave AP, the network can efficiently track the beam and switch to another serving beam. Specifically, exploiting the serving beam ID and direction, the group of beams around the serving beam are used for BT and track the UE. This group of beams can be determined using the predefined codebook of the AP. These beams are the most probable beams, UE will connect with in its next location. These beams are in a form of tiers around the current beam. The proposed scheme uses two tiers to perform beam combing (BC) between them. The number of required tiers used to maintain mmWave link depend on the beamwidth, if beamwidth decrease the number of required tiers is increased. This prediction reduces the search space to find the best beams IDs for the next UE location comparable to exhaustive search. Obviously using the previous UE's beam IDs enables the network to efficiently track the location of a moving UE and maintain the communication direction for the next UE location.

4. SIMULATION RESULTS

In this section, the performance of the proposed and the conventional schemes are evaluated and compared in terms of BT complexity.

4.1. Simulation Parameters and Scenario

TABLE. I MAIN SIMULATION PARAMETERS

Parameter	Value
Num. of APs MmWave	1
TX Power of mmWave AP	10dBm
Height of mmWave AP/UD	3m/ 0.75m
Num. of total beams mmWave AP	91
Φ_{-3dB} /Θ_{-3dB} of mmWave beam	different
UE speed, V	2 m/s
Simulation steps	120
Threshold received power, P_{th}	-75dBm
Threshold received power, P_{mcs0}	-78dBm

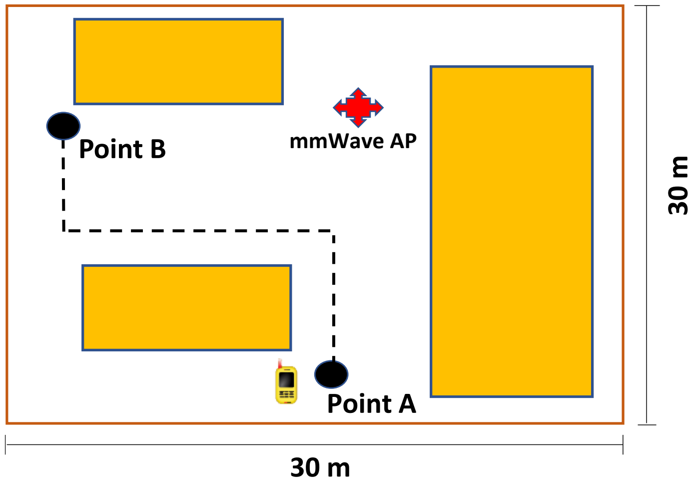

Fig. 4. Simulation area with one deployed mmWave AP.

To evaluate the performance of the proposed scheme, simulations are performed in an outdoor local environment a with area 30x30 meters as shown in Fig. 4. The simulation area is shown in Fig. 4, where the UE is moving from point A to point B with 2 m/s. In this simulation, as shown in Fig. 4, one mmWave AP is deployed to provides the mmWave service for the UE using the different beams directions throughout the target area. However, this scheme can be simply extent to multi-APs scenario. In this simulation, the heights of mmWave AP and the UE are considered to be 3m and 0.75m, respectively. Also, in this paper, the fixed beamforming strategy are considered. specifically, fixed number of beams in fixed directions with a certain beamwidth configured for the mmWave AP. The main simulation parameters are listed in Table I. In the simulation scenario, in the case of quality degradation of link between a UE and a mmWave AP, the network can efficiently track the beam and switch to another serving beam. Specifically, exploiting the serving beam ID and direction, the group of beams around the serving beam are used for BT and track the UE. In the simulation, the received power at the UE is measured periodically at steps of 0.2 m along the UE path. The selection of the duration of the measuring step is based on the time which is required for the UE to pass the beam footprint. If the power of the received power at the UE using the serving beam is dropped below the received power threshold, beam handover decision is initiated. Where, a link re-establish process is performed using the group of the selected beams with tracking scheme. The highly reduction of the BT beams enables the system to efficiently track the beam with the mobile UE.

4.2. mmWave AP Coverage and Beam Configuration Analysis

Generally, as indicated in Section II, the coverage of a mmWave AP is based on the beamwidth. This is because, as described in (2) and (3), the total and the maximum beam gains, G_{dB} and G_m respectively are directly proportional to are the azimuth and elevation half power beamwidths, Φ_{-3dB} and Θ_{-3dB}. Fig. 5 shows the mmWave AP potential transmission range, $\Re_t$, according to (5) for different beamwidths. As shown in Fig.5, the potential transmission range for the mmWave AP is decreased with increasing the beamwidth for zero shadowing term and specific transmitted power and receiver sensitivity values. This is directly coming from the fact that, with increasing the beamwidth its associated maximum gain will be increased. Which in turn allow longer AP transmission range and vice versa.

Figs. 6 and 7 shows the number of beams and tiers for a mmWave AP with different beamwidth values, respectively Besides its effect on the AP transmission range, beamwidths also effect on the total number of beams for a mmWave AP which are needed to cover the whole UE's 3D space. This is because, the with small, configured beamwidths with small footprint, large numbers of beams in different tiers are needed to cover the UE's space. On the other hand, this number of required beams is decreased with increased the beamwidth for the configured beam. This due to with increasing the beamwidth the corresponding coverage area of the beam will be increased which lead to lower number of configured beams in larger number of tiers for span the UE's space. Generally, Fig. 6 and Fig. 7 indicate that total number of beams/tiers for a mmWave AP which are needed to cover the whole UE's space are increased with decreasing the beamwidth and vice versa. For example, with beamwidth 20° the total number of configured beams for a mmWave AP is 91 beams, which is significantly increased to be 1261 beams with decreasing the beamwidth to 5°.

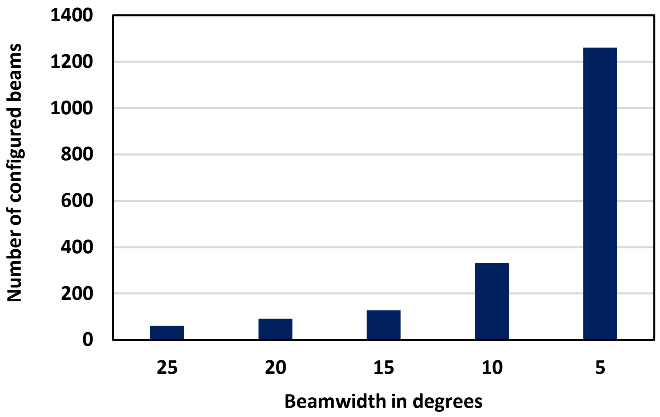

Fig. 6. Number of configured beams for mmWave AP with different beamwidth values.

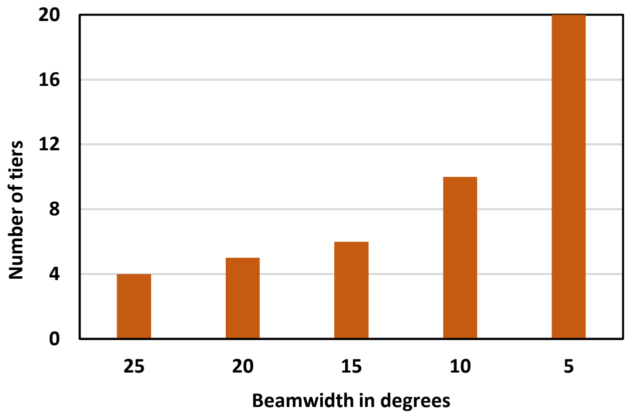

Fig. 7. Number of beams' tiers for mmWave AP with different beamwidth values.

4.3. mmWave Initial access/tracking Simulation Analysis

The evaluation and comparison of the performance of the proposed and the conventional schemes are performed according to two evaluation metrics. The first metric is the average received power at the UE along the moving path with the proposed and the conventional schemes. The second metric is the BT complexity of the proposed scheme and the conventional schemes at the re-establishment process along the UE path.

Fig.8. shows the average received power at UE along user path from point A to point B with 200. It is noted from Fig. 8 that the proposed scheme provides higher average received power for the UE than the conventional scheme along the moving path. This is because with the proposed scheme, the system can fast perform BT with neighbors beams around the serving beam, hence the link quality is preserved. On the other hand, in the conventional scheme the link power will dropped under the receiver sensitivity threshold due to the along time associated with the exhaustive BT. In both scheme the link needs to be re-stablished to maintain its quality. But

this proposes will be less complex with the proposed scheme due to the elimination of the exhaustive BT process. In this paper, to compare the complexity of the proposed and the conventional schemes, the normalized complexity metric is defined as the number of the BT beams of the proposed scheme of the proposed scheme over those of the conventional one. The normalized complexity can be mathematically expressed as follows:

$$\Gamma_C[\%] = \frac{[No.\ total\ BT\ beams]_{Proposed}}{[No.taotal\ BT\ beams]_{Conventional}}\ x100.$$

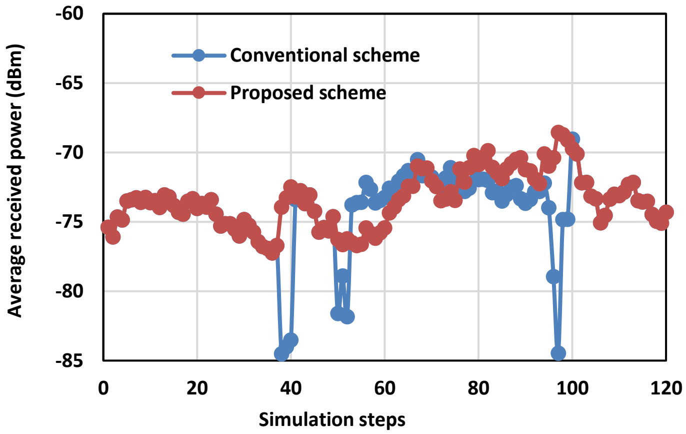

Fig. 8. Average received power along the UE path.

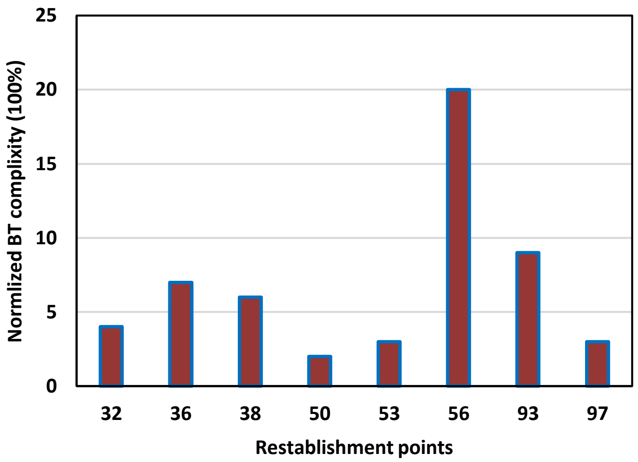

Fig. 9. Normalized BT complexity.

Fig. 9 shows the normalized complexity at the re-establishment points along the UE moving path. It is shown from Fig. 9 that the proposed scheme is highly reduces BT complexity comparable to conventional exhaustive search BT. The proposed BT scheme reduces the BT complexity for UE along its path compare to exhaustive search with about 90%. This high reduction in complexity cause reducing BT setup time and increasing end user throughput. Hence, improving total system performance.

5. CONCLUSION

In this paper, the challenge of robust mmWave communication realization in dynamic environment is considered and an efficient 3D beam tracking scheme for a moving UE is proposed. The proposed scheme is based on exploiting the serving beam ID and direction to narrow the search space for track the UE at the next location specifically, group of beams around the serving beam are used for BT to track the UE and find the next beam. The highly reduction in BT process enables to switching to the next beam fast. The simulation analysis shows the effectiveness of the proposed scheme in reducing the BT complexity for beam tracking. While providing comparable received power levels with the conventional schemes s. for example, using 20° beamwidth, the proposed scheme reduces BT complexity with 90 % comparable to conventional BT. As a future work, the effectiveness of the proposed scheme in facilitating the enabling and integration of mmWave in the current legacy network to pave the way towards 5G can be studied.

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