# Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

**Submission Title:** [A Study on mmWave Beamforming for High-Speed Train Communication]
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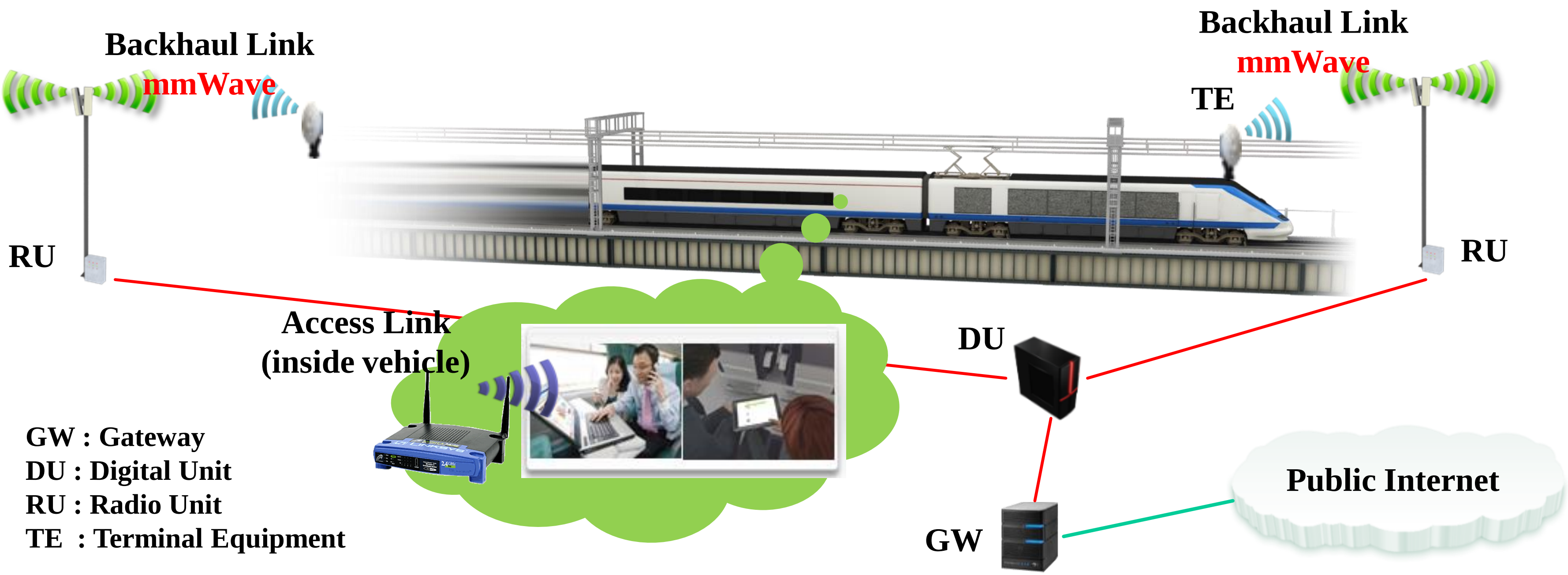
**Abstract:** [A Study on mmWave Beamforming for High-Speed Train Communication]

**Purpose:** [For discussion]

# Contents

# Introduction

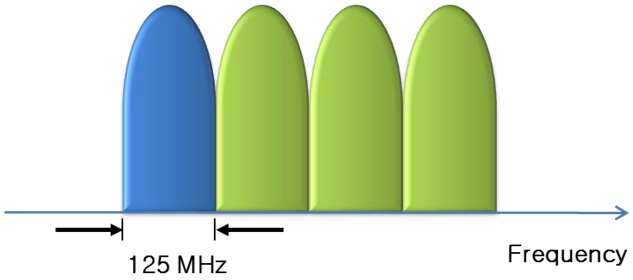
- Hierarchical two-hop network for fast moving vehicles
  - Mobile wireless backhaul link
    - High rate rail communications Interest Group (IG HRRC) : a multi-gigabit-per-second mobile wireless backhaul supporting high-mobility up to 500km/h
  - Access link
    - Small cell (Wi-Fi and femto cell)



# Introduction

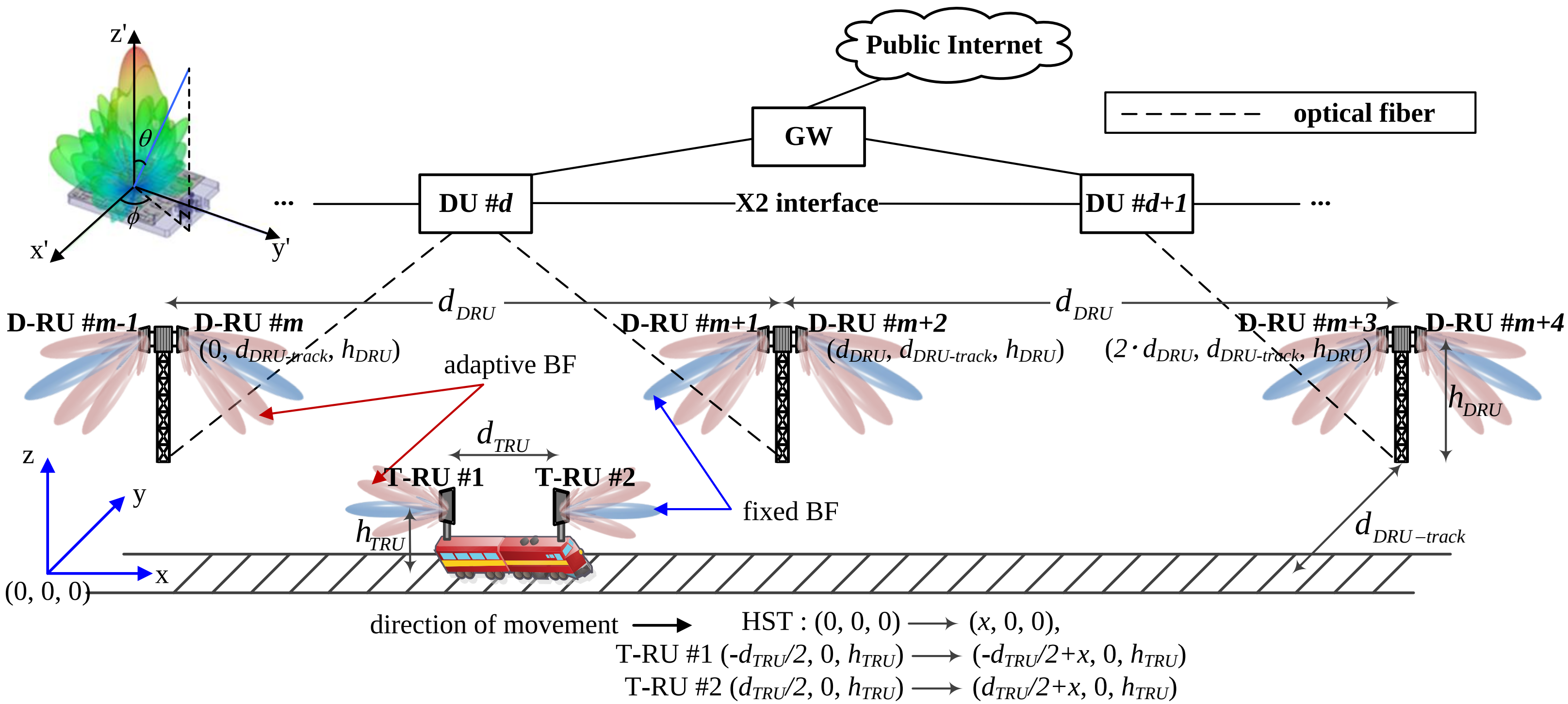
- Various technical challenges and potential solutions
  - Capacity improvement
    - Millimeter-wave due to its vast amount of underutilized spectrum
    - MIMO techniques (polarized antenna)
  - Path loss and atmospheric attenuation of millimeter-wave
    - coverage improvement by using beam-forming technique
  - Inter-carrier interference (ICI) by Doppler effect
    - Proper sub-carrier spacing design for OFDM
    - Millimeter-wave beam-forming techniques → Doppler frequency shift in the frequency domain can be simply overcome by automatic frequency control (AFC)

| ETRI's approach to physical layer design | |
|---|---|
| Mobile Wireless Backhaul Link (Outside Vehicle) | OFDM based on mmWave Beamforming (2-link multi-flow) |
| Data throughput (DL) | **2 Gbps** using 500-MHz bandwidth |
| Spectral efficiency | 4 bps/Hz |
| Mobility Support | 500 km/h |
| User Access Link (Inside Vehicle) | WiFi or Femto |



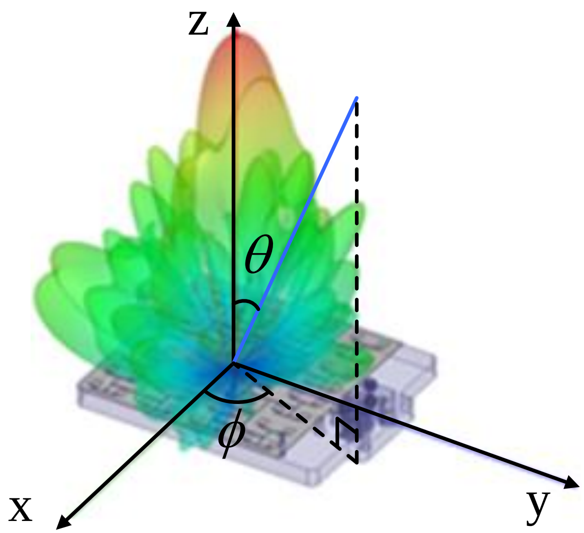
# Network Structure

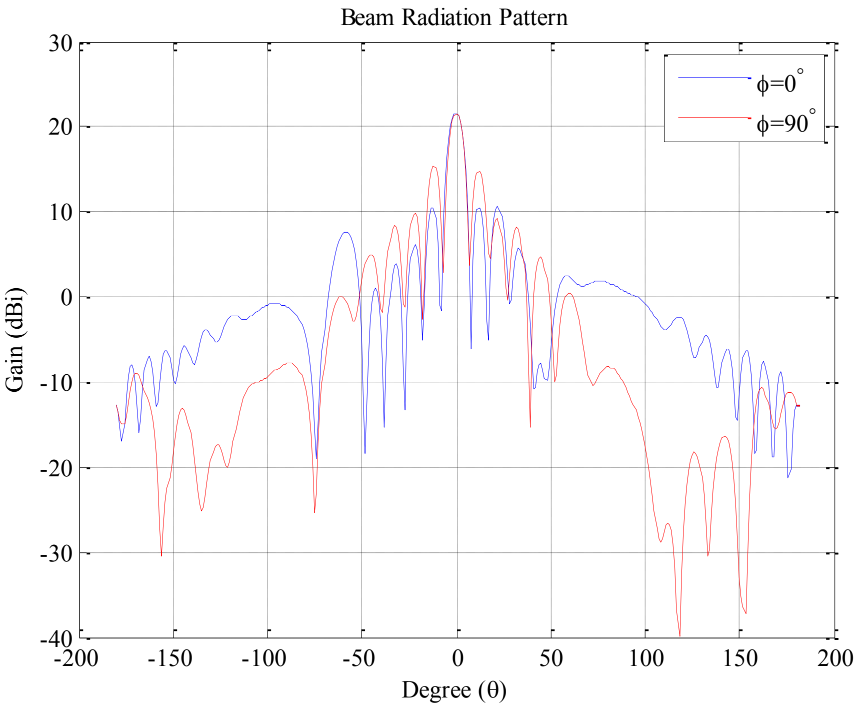
- Millimeter-wave beamforming for HST communication
  - Dual link multi-flow : same radio resources (time and frequency) are assigned to both links



# Beamforming

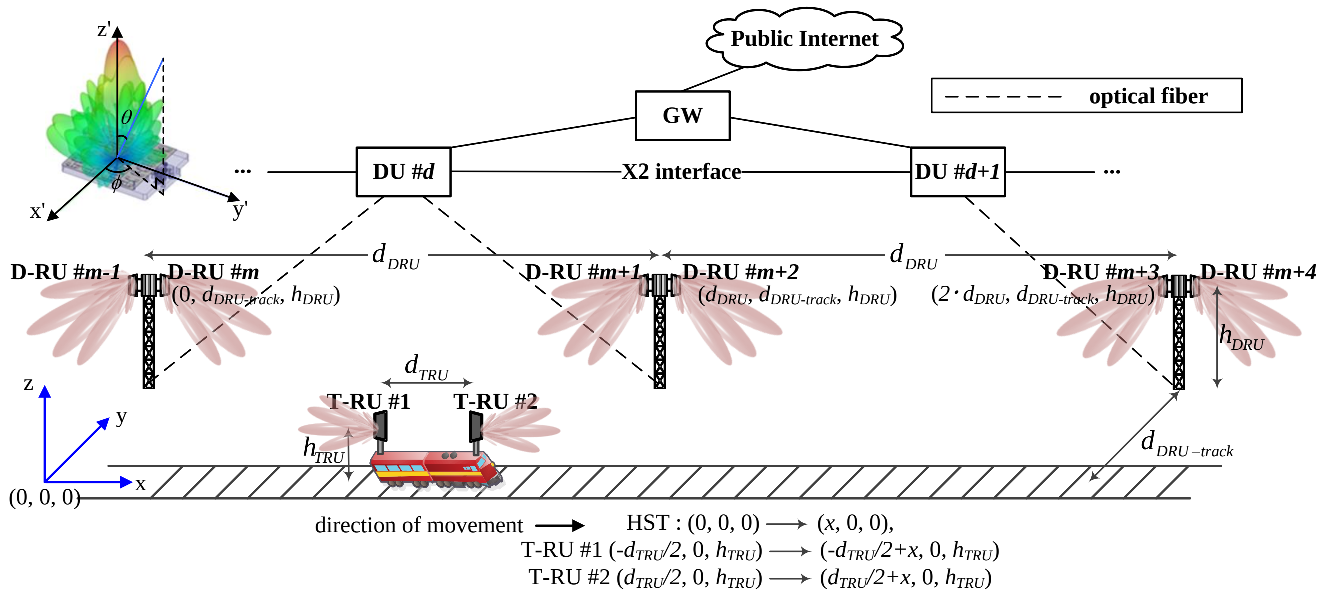
- 3D beam radiation pattern
  - Horizontal and vertical beam width (3dB) : approximately 8 degrees
  - Maximum beamforming gain : 21.58 dBi



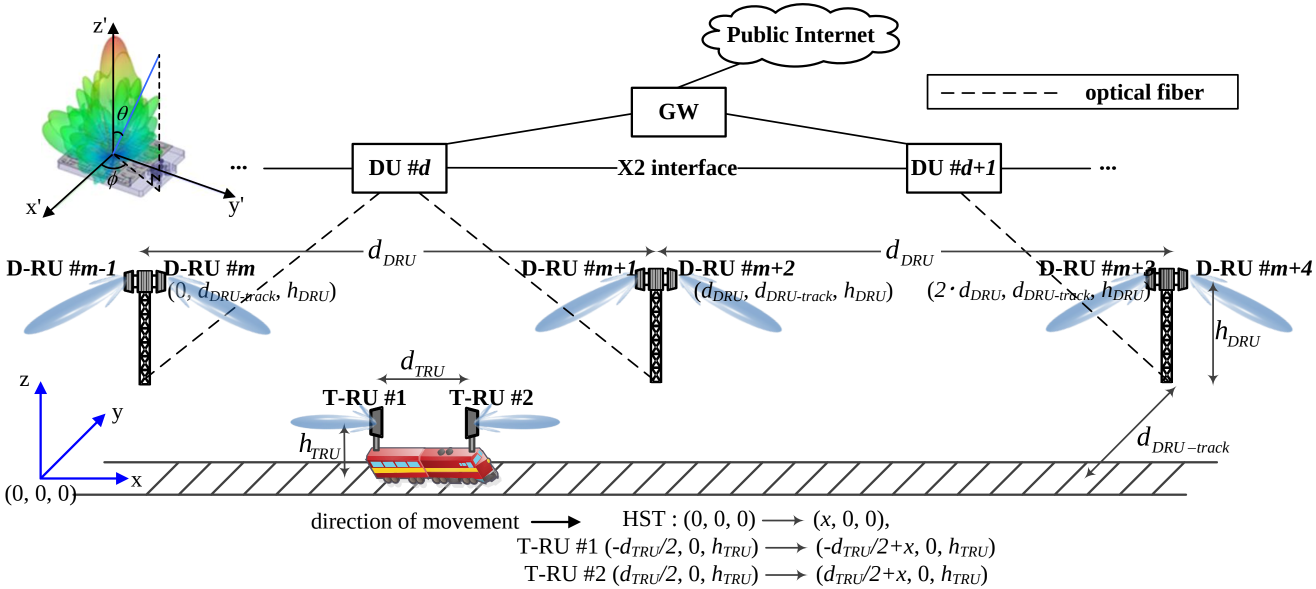
# Beamforming

- Adaptive BF : require automatic tracking of signals of moving targets by continuously updating their parameters based on the received signals
  - Control the beam direction with an accuracy 1˚
  - Beam radiation pattern remains unchanged during beam steering



# Beamforming

- Fixed BF : BF parameters are fixed
  - In the case of TX, the beam direction of *m*-th D-RU and *m*+1-th D-RU is ($d_{RU}$/2, 0, 0) and the beam direction of *m*+2-th D-RU and *m*+3-th D-RU is (3·$d_{RU}$/2, 0, 0)
  - In the case of RX, the beam directions of T-RU 1 and T-RU 2 are simply set to direct in the negative and positive direction of the x-axis respectively



# Simulation

- Simulation scenarios
  - adaptive BF (BS) + adaptive BF (TE)
  - fixed BF (BS) + fixed BF (TE)
  - fixed BF (BS) + adaptive BF (TE)

- Performance evaluation
  - received signal quality
    - $SINR_{dB}(1) = 10log_{10}\left(\frac{SNR(1,1)}{SNR(2,1)+1}\right), SINR_{dB}(2) = 10log_{10}\left(\frac{SNR(2,2)}{SNR(1,2)+1}\right)$
      - $SINR(n) = \frac{P_{RX,D}(n)}{P_{RX,I}(n)+N_{FL}(n)} = \frac{SNR_D(n)}{SNR_I(n)+1}$
      - $SNR_{dB}(m,n) = RSS_{dBm}(m,n) - N_{FL,dBm}(n)$
      - $RSS_{dBm}(m,n) = P_{TX,dBm}(m) + G_{TX,dBi}(m,n) + G_{TX,dBi}(m,n)$
      - $N_{FL,dBm}(n) = -174 + N_{F,dB} + 10log_{10}(W)$

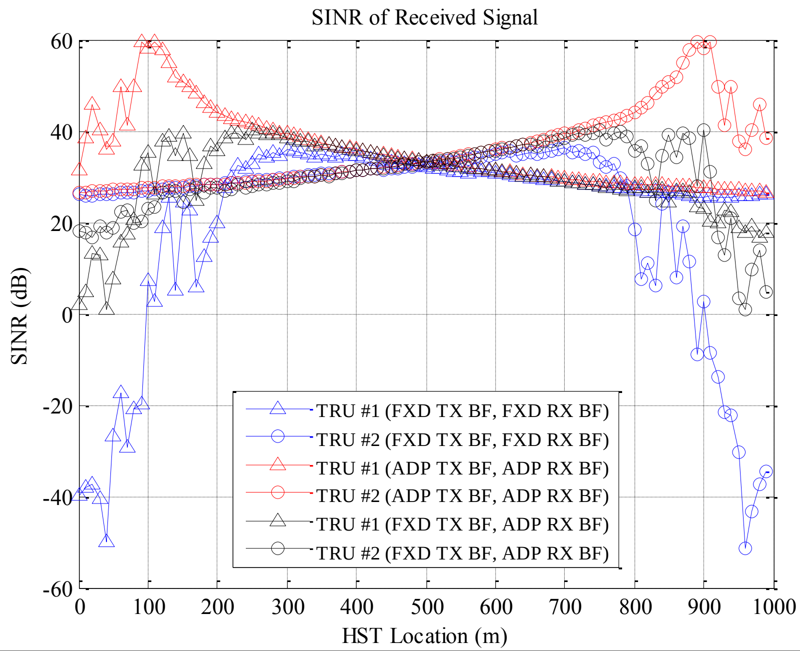
# Simulation

- Major parameters

| Parameters | Values |
|---|---|
| Carrier frequency | $f_c$ = 32 GHz |
| System bandwidth | $W$ = 125 MHz |
| Transmit power | $P_{TX,dBm}$ = 20 dBm |
| Free space path loss [1] | $PL_{dB} = 92.4 + 20 \log f_{c,GHz} + 20 \log d_{km}$ (dB) |
| Noise figure | $N_{F,dB}$ = 8 dB |
| D-RU height | $h_{DRU}$ = 10 m |
| T-RU height | $h_{TRU}$ = 3 m |
| Distance between adjacent D-RUs | $d_{DRU}$ = 1000 m |
| Distance between adjacent T-RUs | $d_{TRU}$ = 200 m |
| Distance between Railway track and D-RUs | $d_{DRU\text{-}track} \in \{10, 50, 100, 150\}$ m |

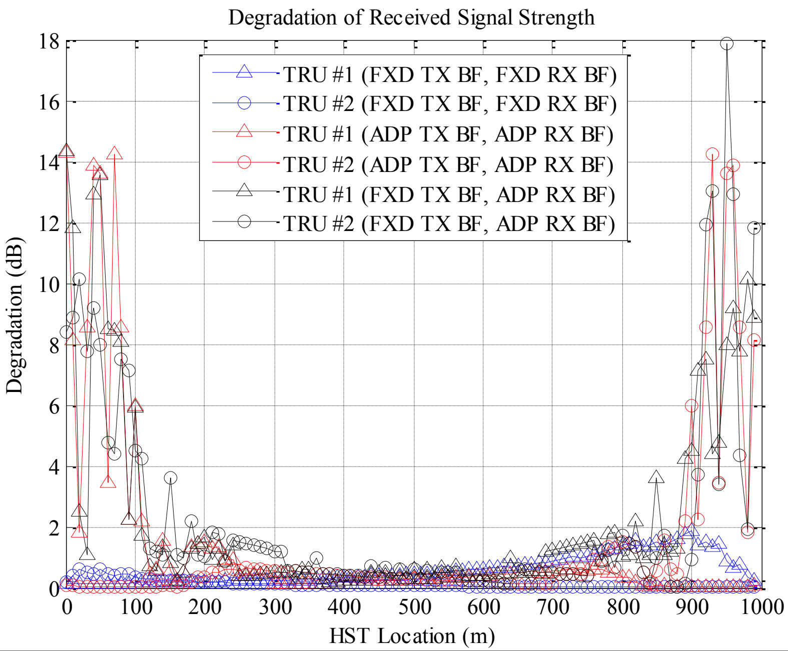
# Simulation

- Simulation results : received signal quality
  - As the HST moves far away from the D-RU, the effect of adaptive BF is negligible whereas it is important to use adaptive BF if the T-RU is close to D-RU



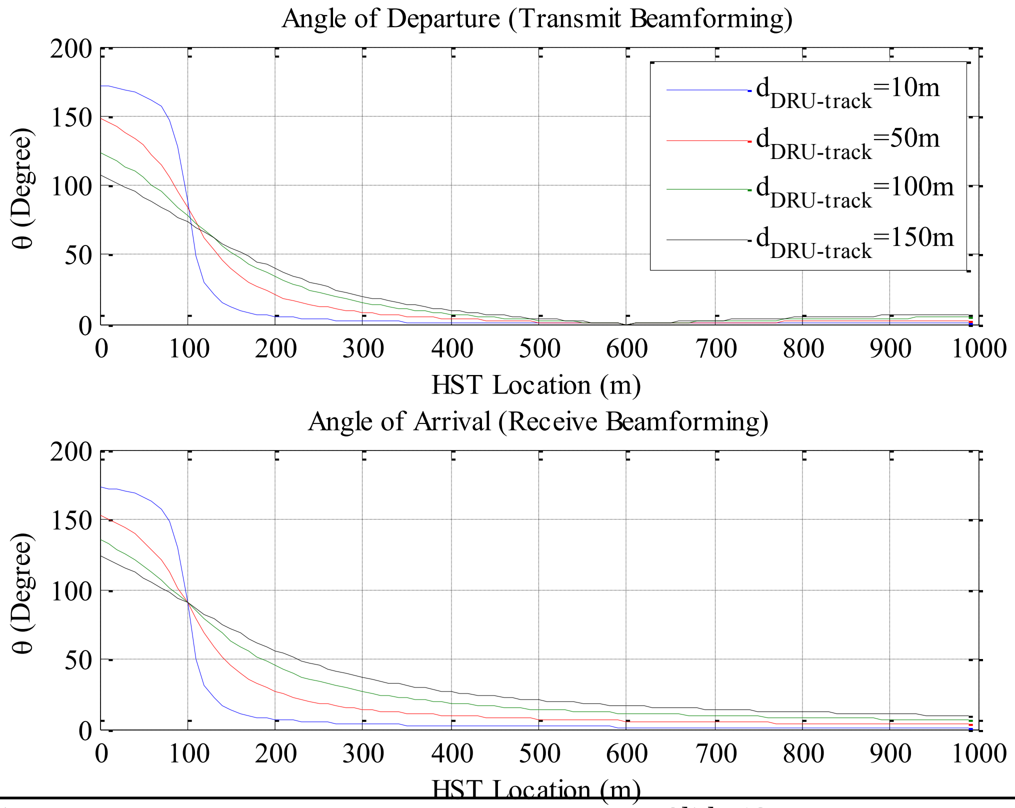
# Simulation

- Simulation results : received signal quality
  - Received signal strength < 2 dB in the HST location from 200m to 800m
    - If the T-RUs are placed sufficiently far away from each other, inter-D-RU interference at each T-RU is significantly reduced with a properly sharp beam pattern designed for both TX and RX side



# Simulation

- Simulation results : AoD, AoA
  - Both vary according to $d_{DRU-track}$
  - $d_{DRU-track}$ : distance between DRU and railway track

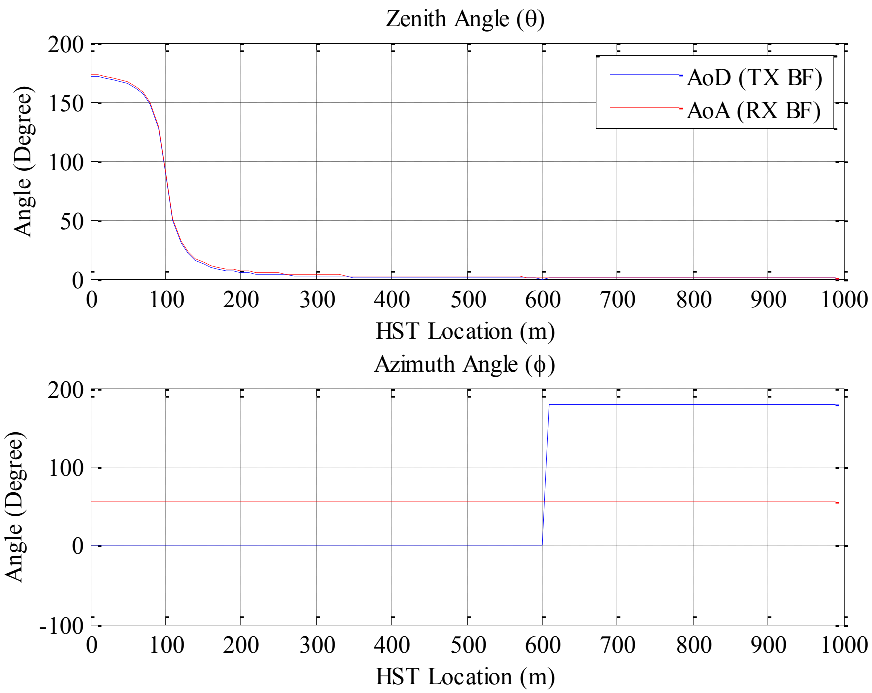


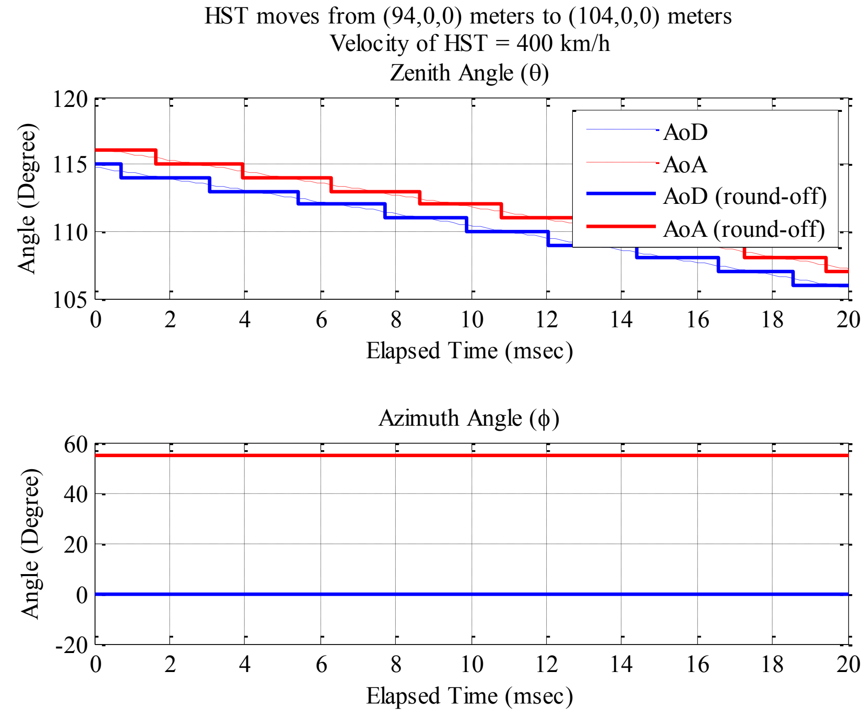

- AoD : Angle of Departure (transmit beamforming)
- AoA : Angle of Arrival (receive beamforming)

# Simulation

- Simulation results
  - $d_{DRU-track} = 10\ m$

- AoD : Angle of Departure (transmit beamforming)
- AoA : Angle of Arrival (receive beamforming)



# Conclusions

- Different BF schemes are appropriate for different HST location
- The fixed BF can achieve very similar performance to that of adaptive BF in most of time
  - giving a valuable insight into designing the mmWave BF based HST communication system from feasibility and implementation perspective
- As future works, it is worth to study the performance of adaptive BF in the presence of calibration error and the HST communication system in various environments including the case of HST running along the curved line.

# References

1. ITU-R P.525-2, "Calculation of free-space attenuation"