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

Submission Title: Ray-tracing based Study on Mobile Channel in Typical Urban Environment with Various Beamforming Strategies at 32 GHz

Date Submitted: 5 November, 2015

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Abstract: This document presents the ray-tracing simulation results on mobile channel in typical urban environment with various beamforming strategies at 32 GHz. The main channel characteristics imply that the fixed beamforming is appropriate. Moreover, strong fading resulting from multipath propagation is critical, and therefore, ray-tracing simulator shall be employed for generating a realistic channel.

Purpose: This document suggests the necessary channel simulation method, the appropriate beamforming strategy, and the possible handover and MIMO solutions for the mobile channel at 32 GHz.

Outline

- System setup
- Ray-tracing simulation
- Channel characteristics and insights
- Conclusion and future work

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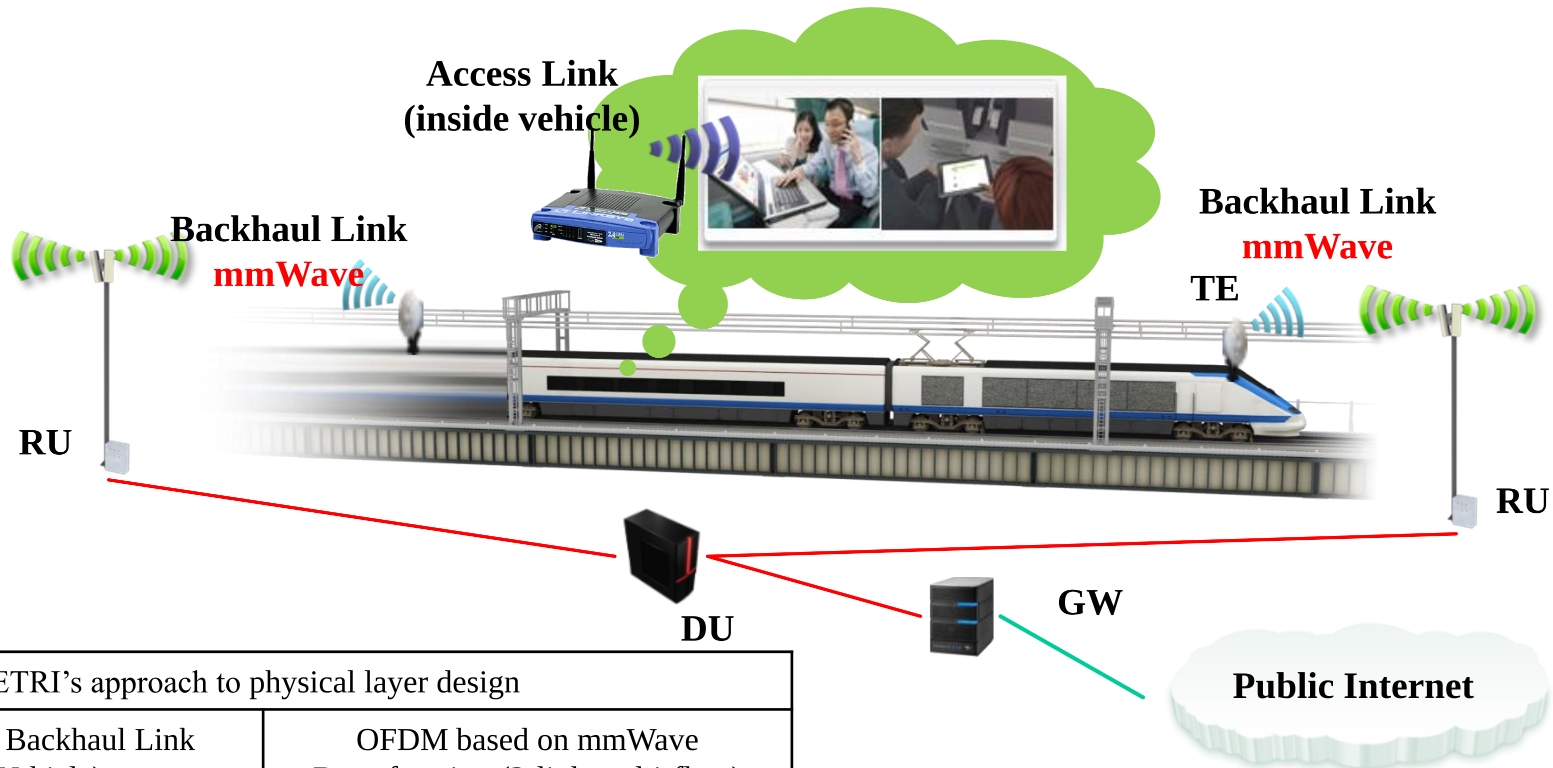
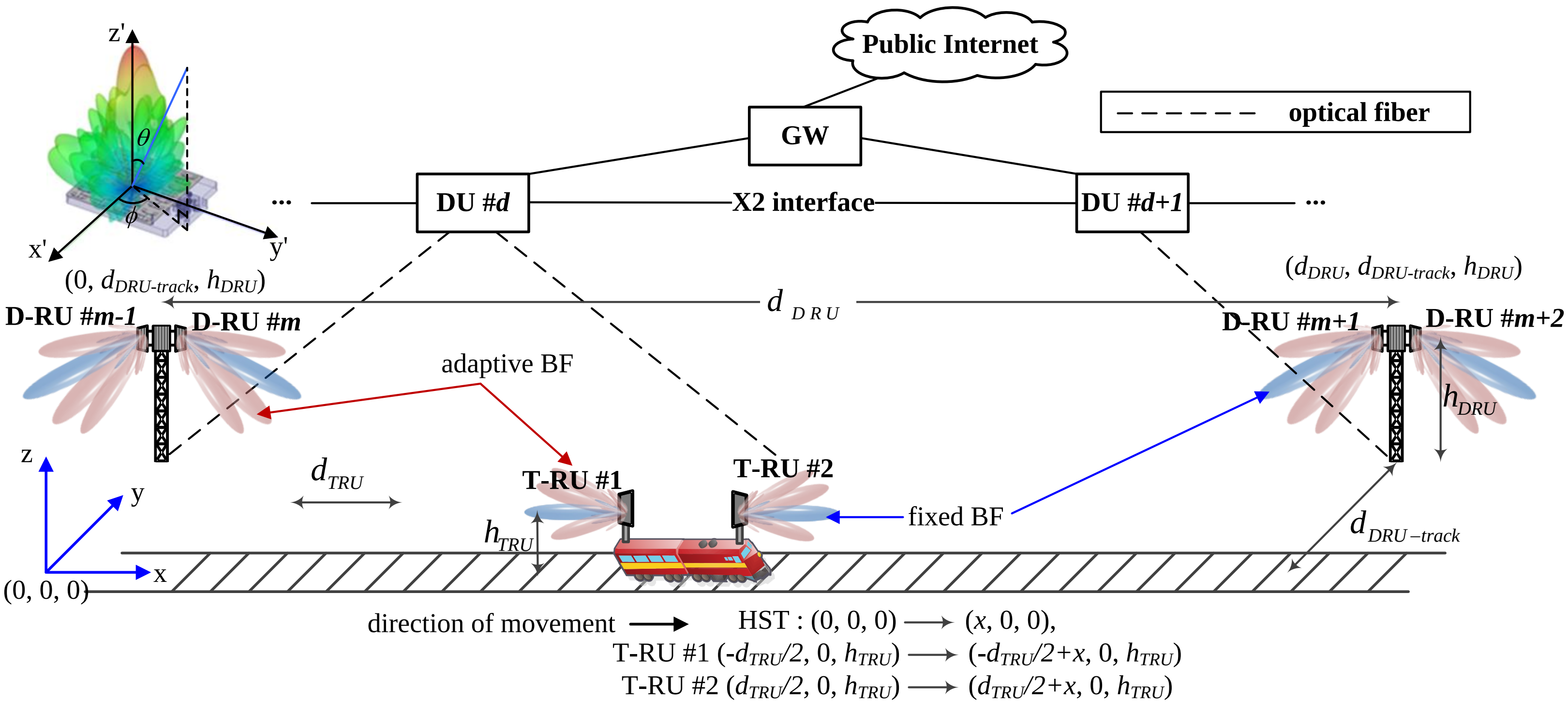


ETRI's approach to physical layer design	
Mobile Wireless Backhaul Link (Outside Vehicle)	OFDM based on mmWave Beamforming (2-link multi-flow)
Data throughput (DL)	**2 Gbps** using 500-MHz bandwidth
Spectral efficiency	4 bps/Hz
Mobility Support	500 km/h
User Access Link (Inside Vehicle)	WiFi or Femto

GW : Gateway
DU : Digital Unit
RU : Radio Unit
TE : Terminal Equipment

Millimeter-wave beamforming for HST communication

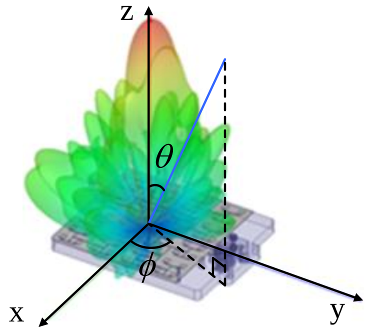
- Dual link multi-flow : same radio resources (time and frequency) are assigned to both links

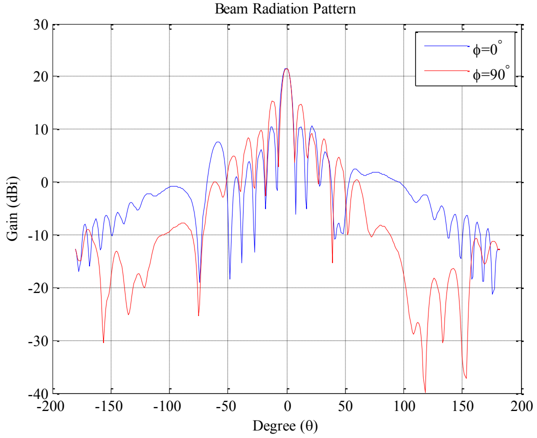


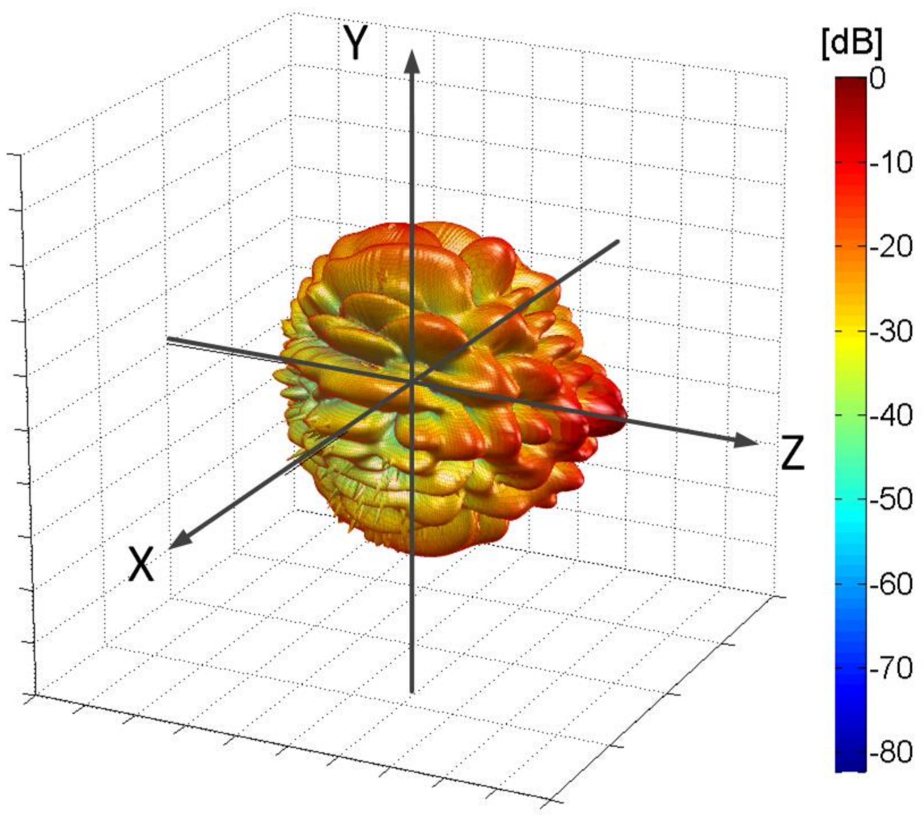
3D beam radiation pattern

Horizontal and vertical beam width (3dB) : approximately 8 degrees

Maximum beamforming gain : 21.58 dBi







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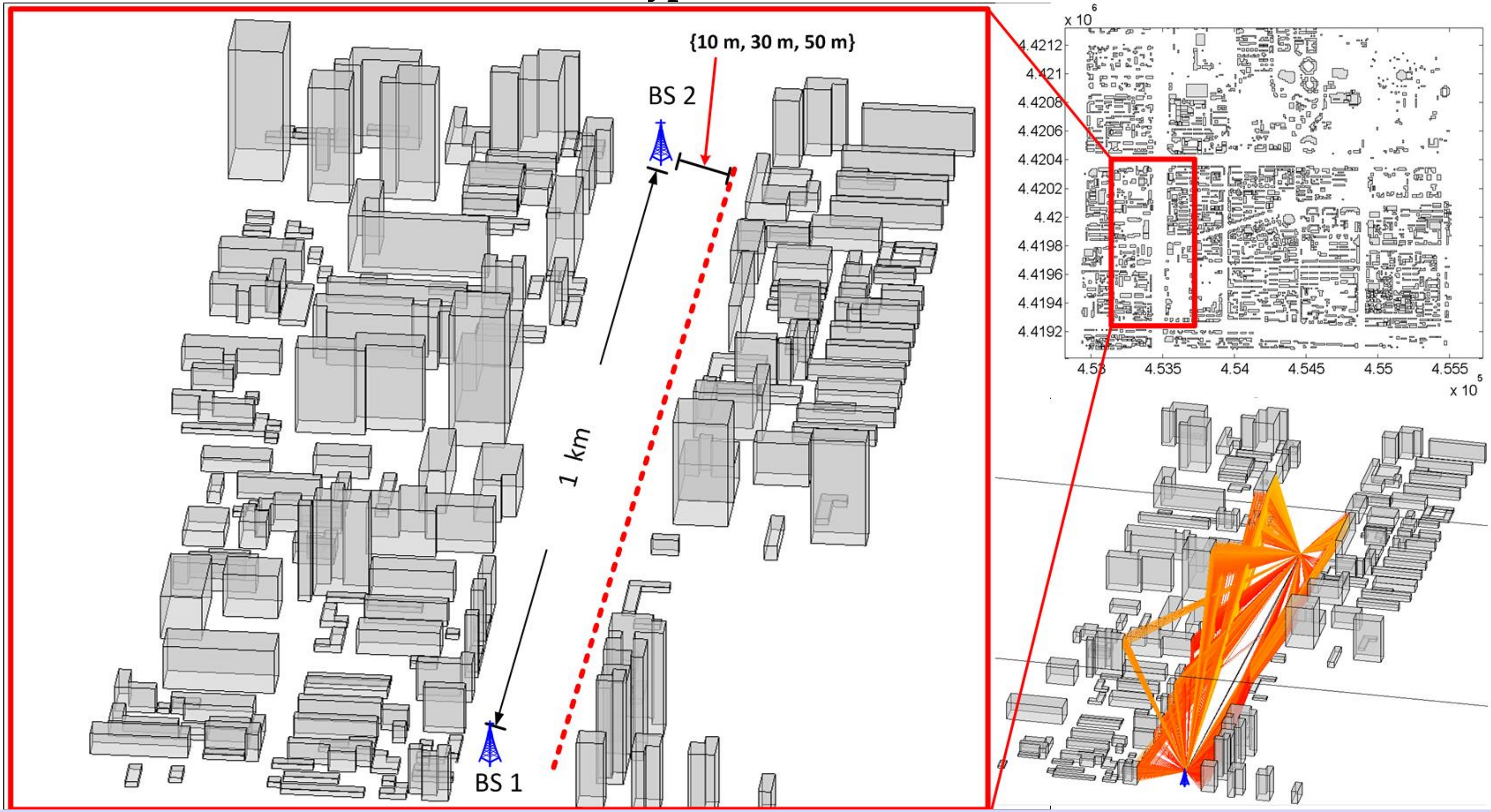
Simulation scenario – typical urban environment



- Simulation scenario is set as a part of urban in real Beijing city. The distance between BS1 and BS2 is 1 km. The red dotted line indicates the track of HST between two BSs.
- $d_{DRU\text{-}track}$ ={10 m, 30 m, 50m} .
- The build materials are set as glass, concrete, brick and metal.

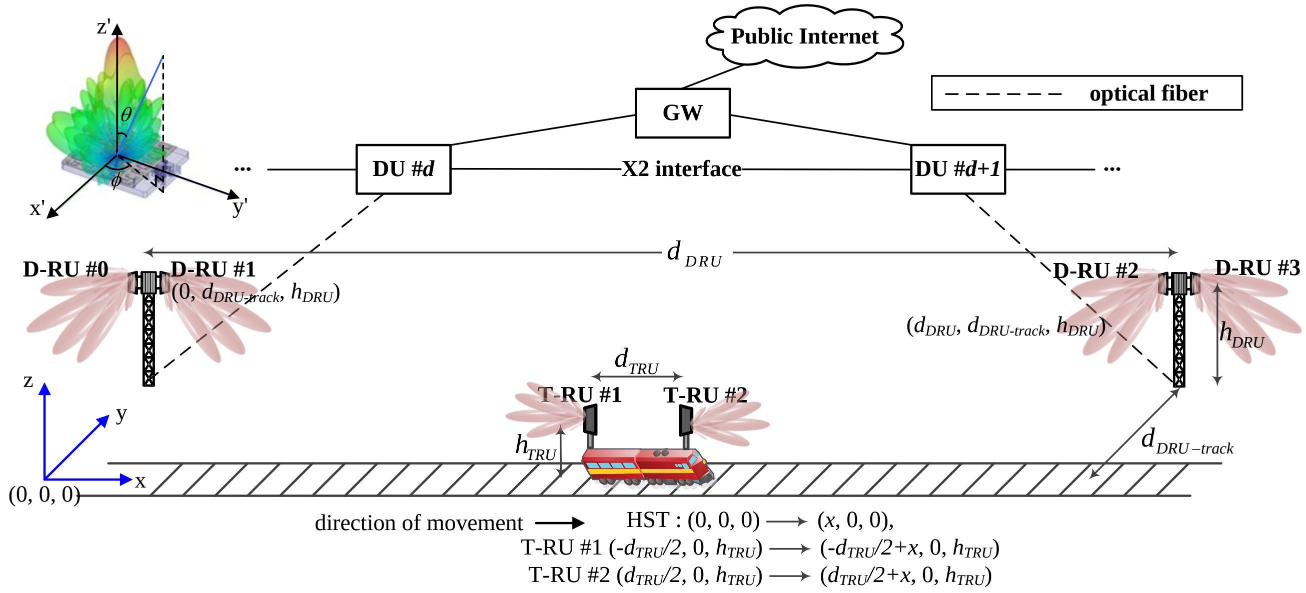
Parameters	Values
Carrier frequency	f_c = 32 GHz
System bandwidth	W = 125 MHz
Transmit power	$P_{TX,dBm}$ = 20 dBm
Noise figure	$N_{F,dB}$ = 8 dB
D-RU height	h_{DRU} = 10 m
T-RU height	h_{TRU} = 3 m
Distance between adjacent D-RUs	d_{DRU} = 1000 m
Distance between adjacent T-RUs	d_{TRU} = 200 m
Distance between Railway track and D-RUs	$d_{DRU\text{-}track} \in \{10, 30, 50\}$ m
Building materials (complex permittivity)	Metal (1-10^7i) ; Concrete (5.31-0.0214i) ; Brick (3.75-0.1507i); Glass (6.27 – 0.1507i) *
Building materials existing proportions	Metal (10%) ; Concrete (30%); Brick (30%); Glass (30%)

Speed of train: 360 km/h

*: Recommendation ITU-R P.1238-7-EM Property

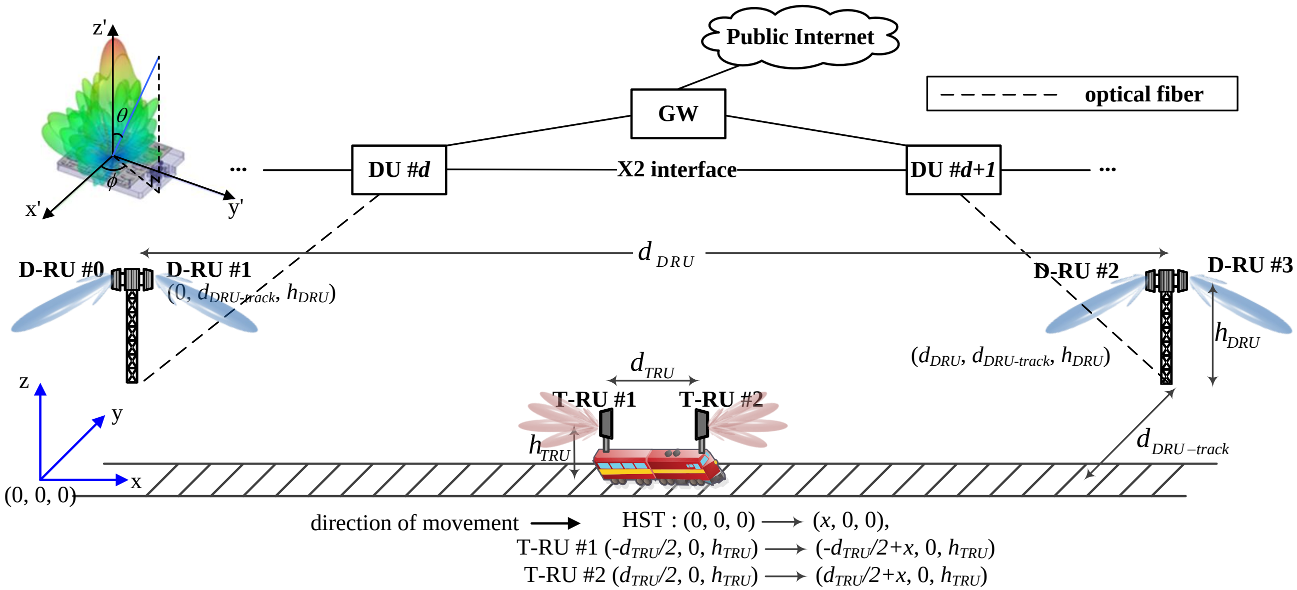
Adaptive Tx BF and Adaptive Rx BF (ADP Tx BF, ADP Rx BF)

- Require automatic tracking of signals of moving targets by continuously updating their parameters based on the received signals in both Tx and Rx sides.
  - Control the beam direction with an accuracy 1˚
  - Beam radiation pattern remains unchanged during beam steering



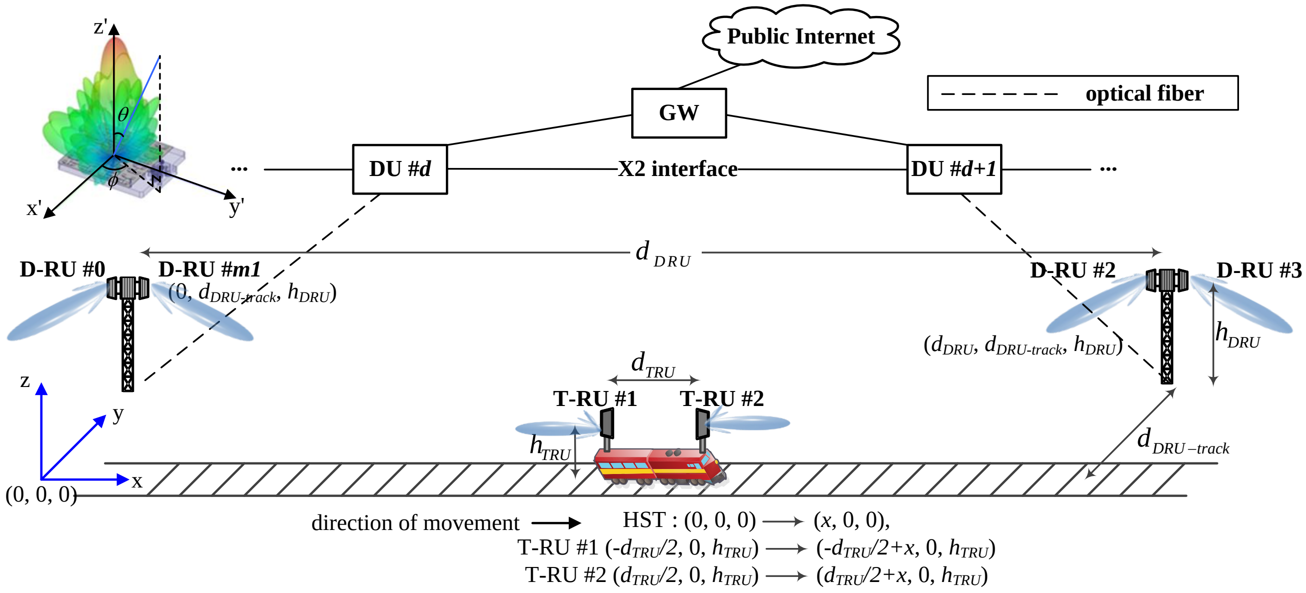
Fixed Tx BF and Adaptive Rx BF (FXD Tx BF, FXD Rx BF)

- In the case of Rx, it requires automatic tracking of signals of moving targets by continuously updating their parameters based on the received signals.
- In the case of TX, the beam direction of D-RU 1 and D-RU 1 is (d_{RU}/2, 0, 0)



Fixed Tx BF and Fixed Rx BF (FXD Tx BF, FXD Rx BF)

- In the case of TX, the beam direction of D-RU 1 and D-RU 1 is (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



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

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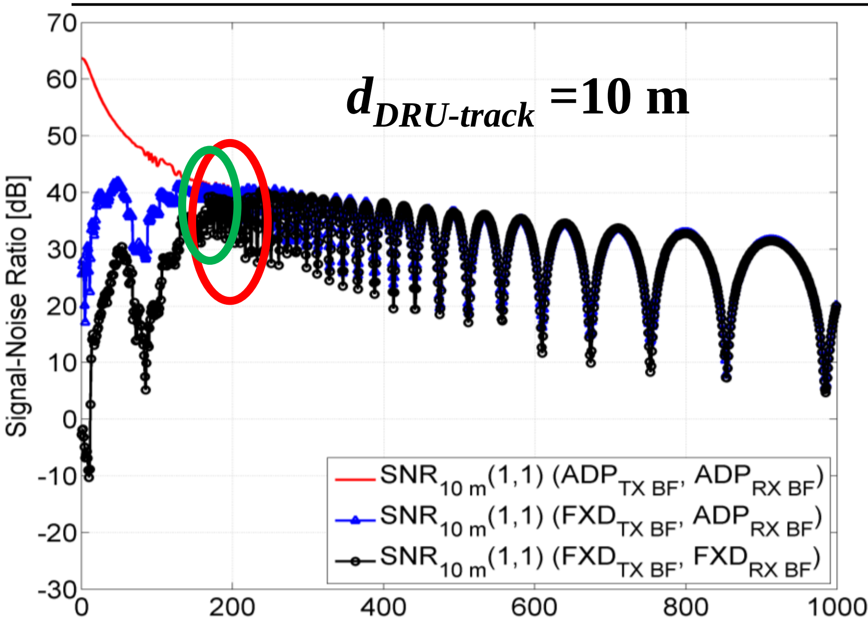
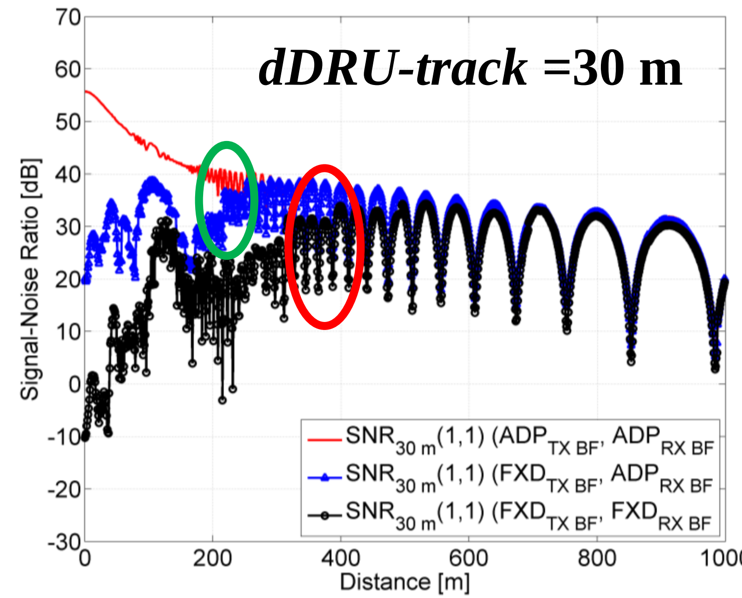
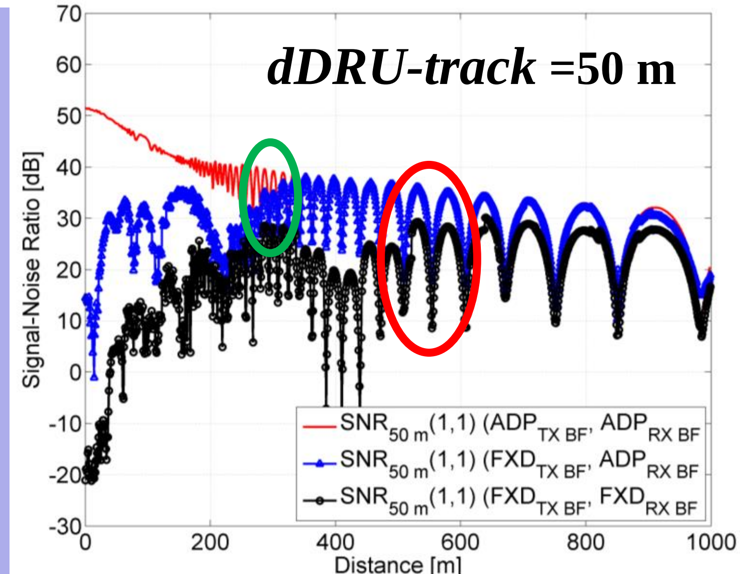


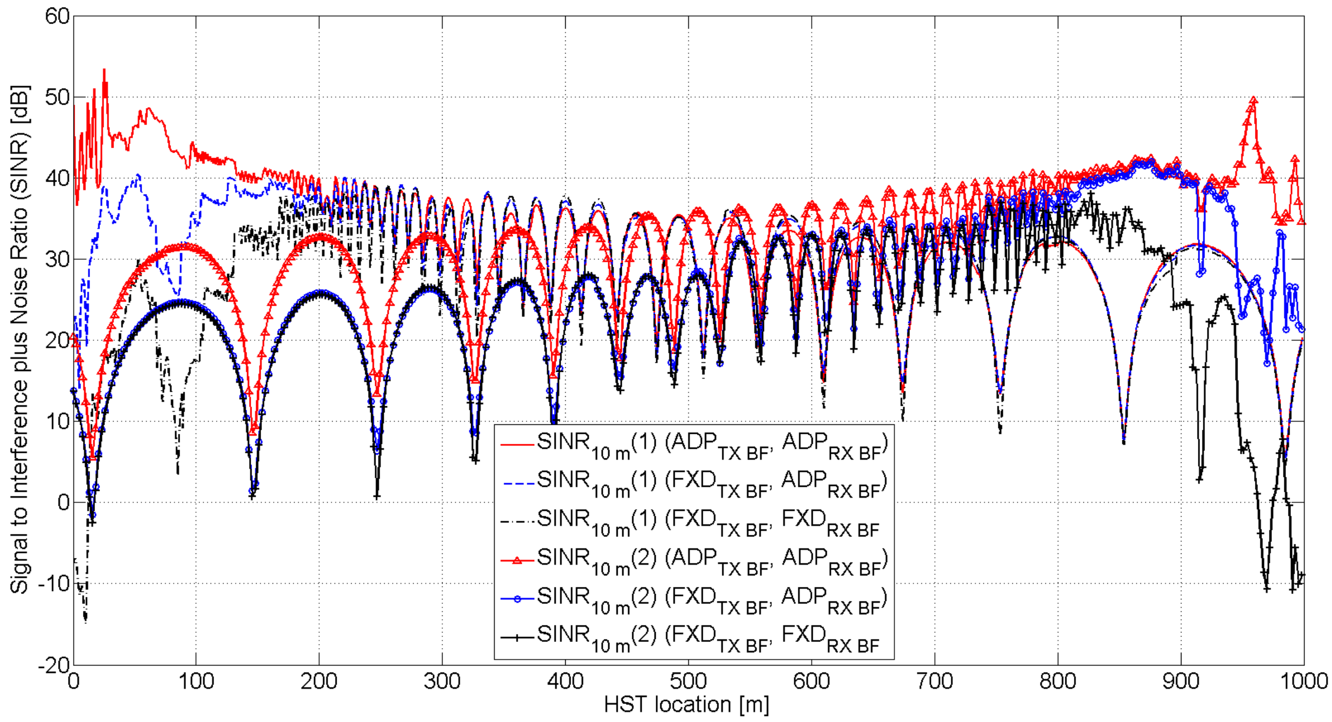




In the typical urban scenario, the adaptive BF on both sides provides the best channel:

- No matter for the fixed BF on Tx and adaptive BF on Rx, or the fixed BF on both sides, the distance between BS and rail is better to be shorter (green and red circles indicate the location since where the corresponding BF strategy provides the channel as good as adaptive BF on both sides).
- Thus, $d_{DRU\text{-}track}$ =10 m is investigated in this work.

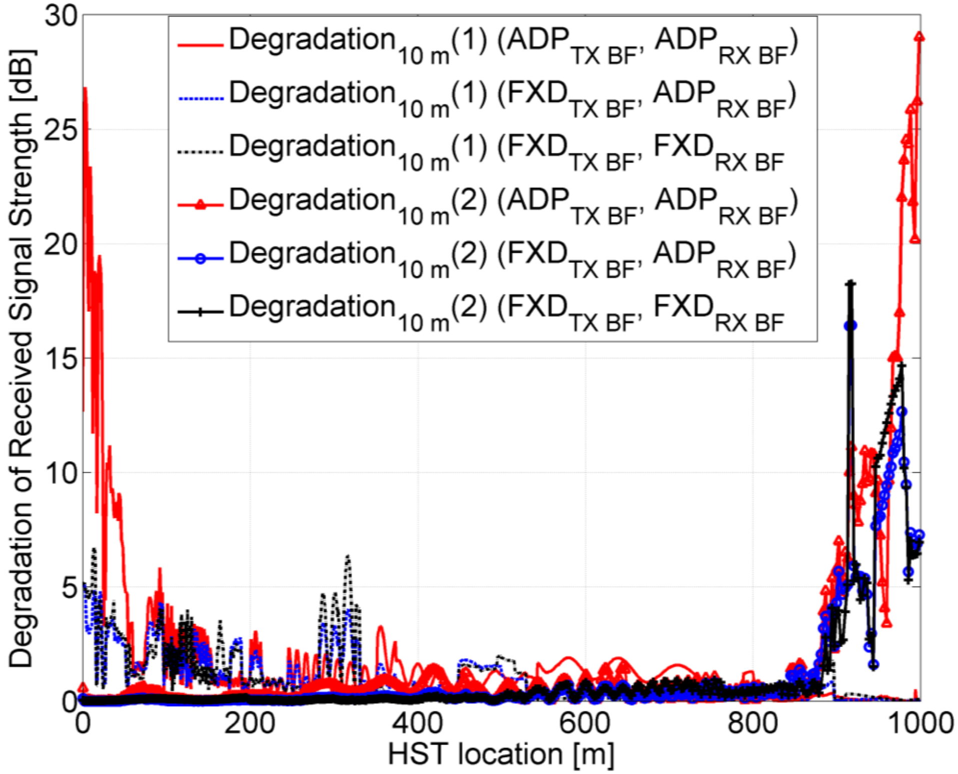
- Simulation results: SINR
  - As the train moves far away from the Tx, the effect of adaptive BF is negligible.
  - When the Rx is close to Tx, it is important to use adaptive BF, OR, make a handover.

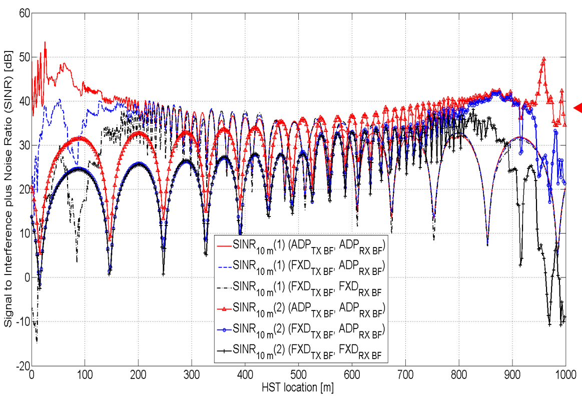


Simulation results : received signal quality

Degradation of received signal strength < 5 dB in the train location from 100m to 900m

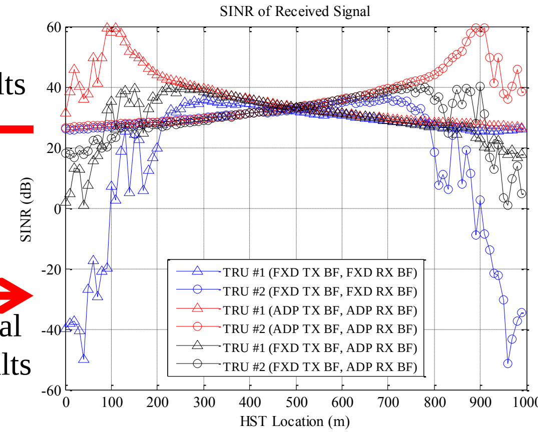
If the Txs are placed sufficiently far away from each other, inter-Tx interference at each Rx is significantly reduced with a properly sharp beam pattern designed for both TX and RX side

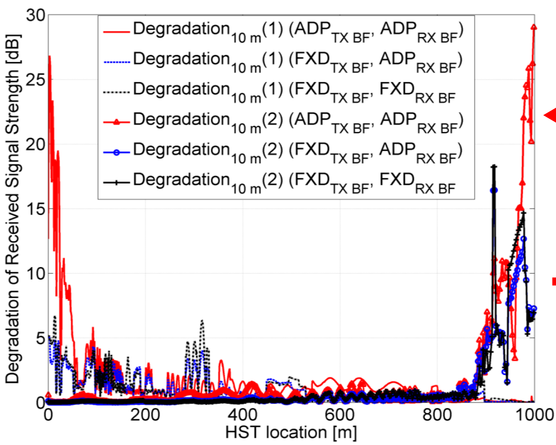




RT results

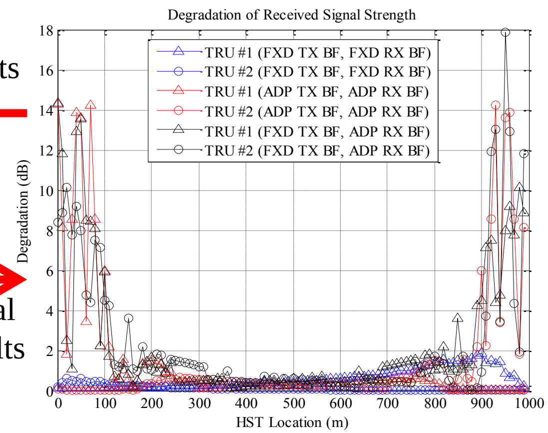
Empirical PL results





RT results

Empirical PL results

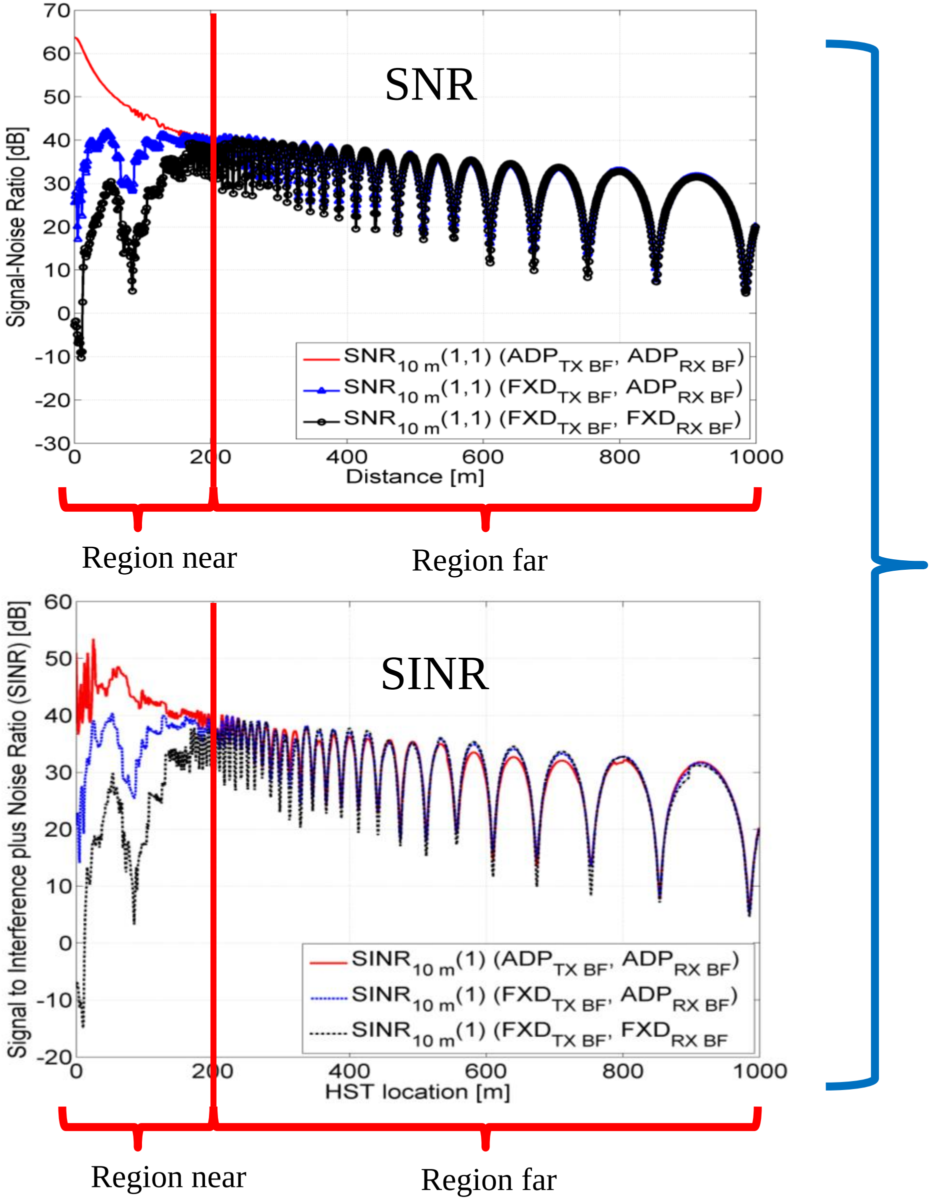


Same conclusions:

- Fix Tx BF and Fix Rx BF system setup can support good coverage when Rx is not close to Tx.
- For Link between Tx and Rx, 200 m is an important boundary for dividing different BF strategies.
- When distance between Tx and Rx is shorter than 200 m, the SINR and degradation of different BF strategies fluctuate variably.
- When distance between Tx and Rx is larger than 200m, the SINR and degradation of different BF strategies are almost the same.
- Using Fixed BF in both Tx and Rx is enough for system design. However, an advanced handover strategy should be used to stabilize system communication links.

Further conclusions:

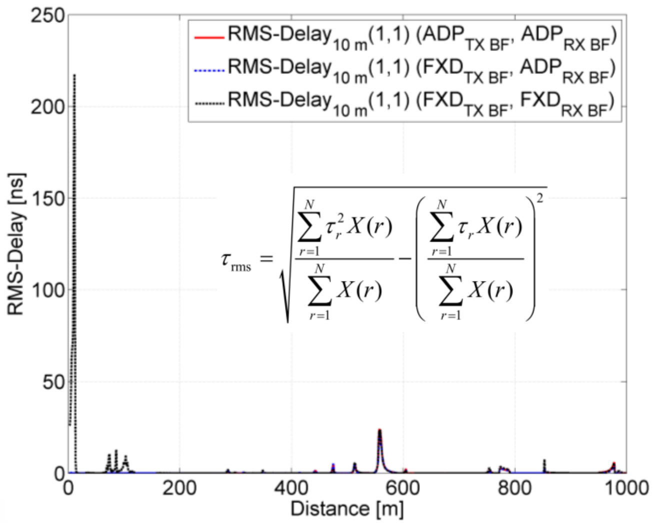
- When distance between Tx and Rx is large than 200 , the simulation results from RT illustrate that the received power of BF strategies suffer severely deep fading. Thus, MIMO should be used to get diversity gain against the deep fading.
- The degradation may be more severe in realistic radio channel due to the inter-Tx interference at each Rx.
- The handover strategies should be designed properly to avoid uncertain fading.

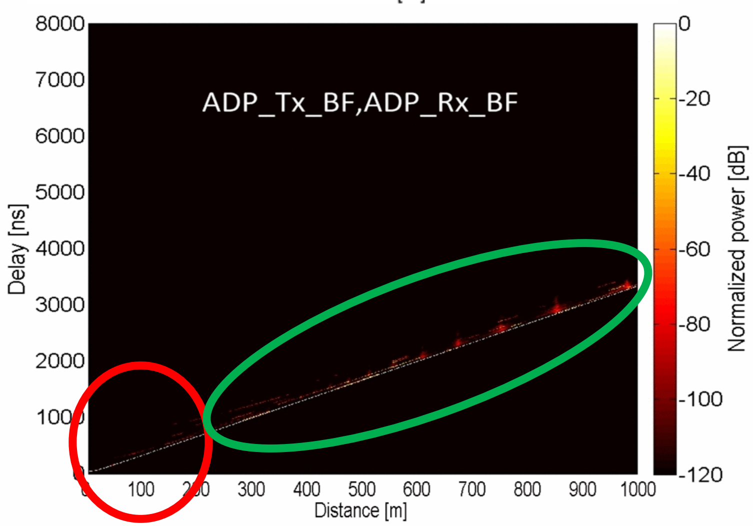


Region Definition

- Two regions are defined according to the SNR and SINR. The Region near is considered as the fluctuation of received power varies completely different from the fluctuation of received power in Region far. The reason for variations in Region near is stemming from the dominant paths which suffer different attenuation through the antenna pattern at different angles.
- The boundary between two regions is defined as 200m between Tx and Rx.

RMS Delay Spread

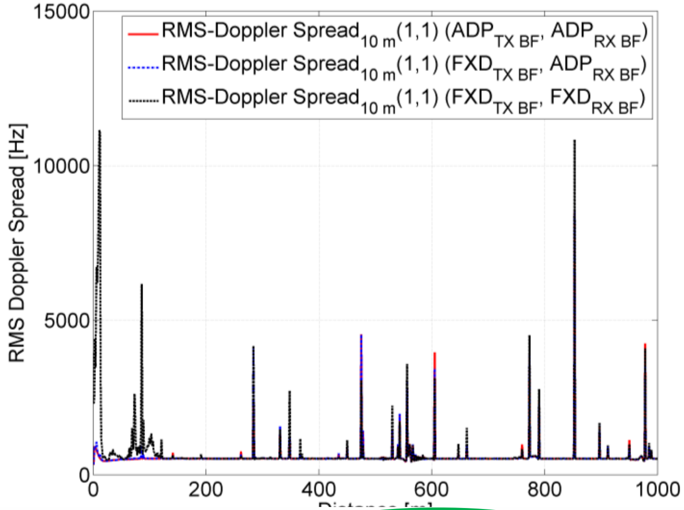


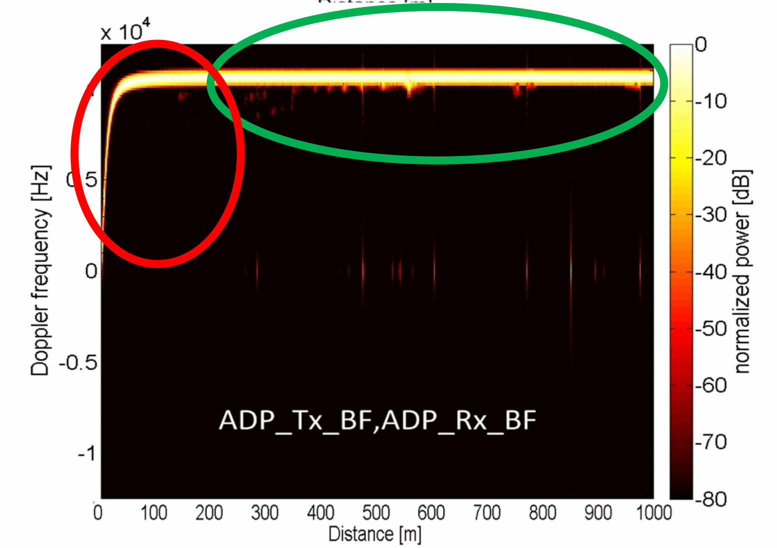


RMS-delay [ns]	$ADP_{Tx} - ADP_{Rx}$		$FXD_{Tx} - ADP_{Rx}$		$FXD_{Tx} - FXD_{Rx}$	
Region:	Region near	Region far	Region near	Region far	Region near	Region far
Minimum	3.97e-4	6.96e-5	6.86e-4	8.99e-5	4.78e-4	4.02e-5
Mean value	0.0049	0.4716	0.0223	0.4366	5.3466	0.4999
Maximum	0.0598	24.131	0.5079	23.382	217.68	23.940

- **ADP Tx, ADP Rx**: very short delay spread in both Region near and Region far, because the severe attenuations are added to the rays which are out of the antenna mainlobes. Thus, the inter-symbol interference (ISI) will be not introduced → High symbol rate .
- **FDX Tx, ADP Rx**: Delay spread is very similar to ADP Tx, ADP Rx in Region far. Even though, in Region near, the delay spread increases, the ISI still does not bother→ High symbol rate
- **FDX Tx, FXD Rx**: Delay spread is very similar to ADP Tx, ADP Rx in Region far. But in Region near, The delay spread suffers severely changes. The symbol rate will drop when high ISI happens.
- **If the FDX Tx, FXD Rx BF strategy is used, the handover shall be done in Region near.**

Doppler Spread

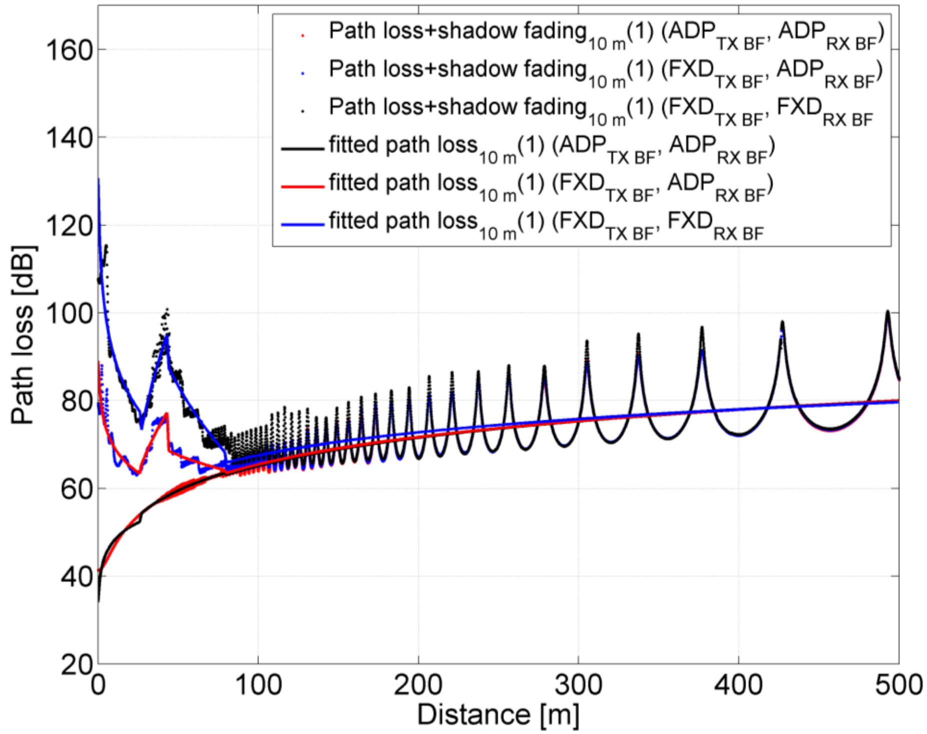




RMS doppler spread [Hz]	$ADP_{Tx} - ADP_{Rx}$		$FXD_{Tx} - ADP_{Rx}$		$FXD_{Tx} - FXD_{Rx}$	
Region:	Region near	Region far	Region near	Region far	Region near	Region far
Minimum	326.65	407.13	339.09	407.14	483.18	408.01
Mean value	326.65	572.89	530.68	573.33	**1051.8**	581.83
Maximum	921.33	8566.8	1066.2	8579.1	**11146**	1084.4

- **ADP Tx, ADP Rx**: Very short Doppler spread in both Region near and Region fad at 32 GHz.
- **FDX Tx, ADP Rx**: Doppler spread is very similar to ADP Tx, ADP Rx in both Region far and Region near.
- **FDX Tx, FXD Rx**: Doppler spread is very similar to ADP Tx, ADP Rx in Region far. But in Region near, The mean Doppler spread is almost doubled. The Maximum of Dopper spread booms to 11 kHz.
- **If the FDX Tx, FXD Rx BF strategy is used, the handover shall be done in Region near.**

Path loss and shadow fading



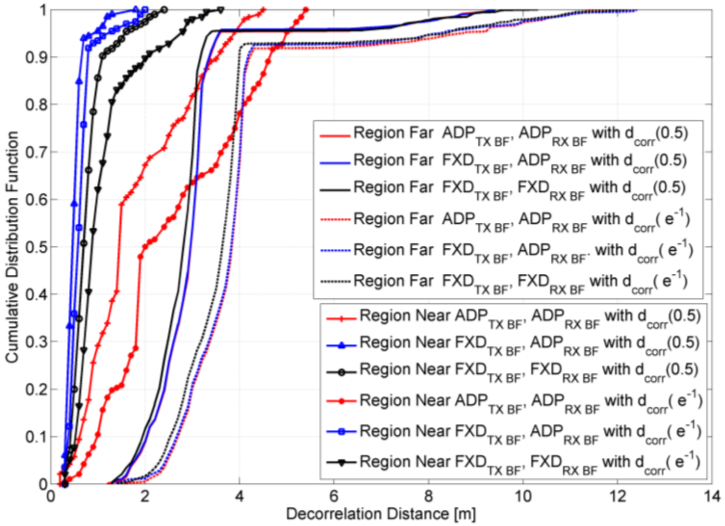
$$L(d) = \bar{L}(d_0) + 10n\lg\left(\frac{d}{d_0}\right) + X_\sigma$$

n	Path loss exponent
X_σ	Shadow fading

RMS doppler spread [Hz]	$ADP_{Tx} - ADP_{Rx}$	$FXD_{Tx} - ADP_{Rx}$	$FXD_{Tx} - FXD_{Rx}$
Region:	Region far	Region far	Region far
n	Very simliar, around 2		

- In the RT simulation, massive deep fadings of received power are obtained. They may cause communication link interrupted.
- Such fading property cannot be reflected by using free space path loss formula. → Ray-tracing simulation is necessary.
- It is obviously that the deep fading in Region far is severe. The MIMO technologies should be employed to get enough diversity gain.

Decorrelation distance of shadow fading



- **ADP Tx, ADP Rx:** channel is highly correlated. To get a diversity gain, 2 m and 4 m separation between adjacent MIMO antennas should be considered in Region near and in Region far, respectively.
- **FDX Tx, ADP Rx**: channel is lowly correlated in Region near. So 1 m separation between adjacent MIMO antennas should be considered in region near.
- **FDX Tx, FXD Rx**: if handover is done to avoid Region near, the distance between two adjacent MIMO antennas should be 4 m in the Region far.

Decorrelation Distance [m]	$ADP_{Tx} - ADP_{Rx}$				$FXD_{Tx} - ADP_{Rx}$				$FXD_{Tx} - FXD_{Rx}$			
Region:	Region near		Region far		Region near		Region far		Region near		Region far	
Threshold	d_{corr} (0.5)	d_{corr} (e^{-1})	d_{corr}(0.5)	d_{corr} (e^{-1})	d_{corr} (0.5)	d_{corr} (e^{-1})	d_{corr} (0.5)	d_{corr} (e^{-1})	d_{corr} (0.5)	d_{corr} (e^{-1})	d_{corr} (0.5)	d_{corr} (e^{-1})
50%	1.500	2.000	3.003	3.904	0.5000	0.600	3.0034	3.904	0.700	0.900	2.903	3.704
90%	3.600	4.700	3.404	4.304	0.7000	0.800	3.4039	4.205	1.100	2.100	3.203	4.004
Mean	1.831	2.665	3.072	4.056	0.5485	0.674	3.0525	4.003	0.815	1.129	2.944	3.839
Max	4.500	5.400	9.410	12.41	1.8000	2.000	9.4106	12.414	2.400	3.600	10.31	12.214

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Conclusion and future work

- Fixed beamforming used on both Tx and Rx is enough for stable communication link with advanced handover strategies.
- The deficiencies of fixed beamforming mainly appear in Region near. So the handover of communication link should be done in Region near.
- Using free space path loss formula to study channel characteristics is deficient. Many channel characteristics (shadow fading, K-factor, Doppler, delay, etc.) can be captured by using ray-tracing simulator.
- The MIMO antennas should be employed to get diversity gain against the deep fading of multipath propagation. The distance between ajacent antennas should be large than 4 m in Region far (FDX Tx, FXD Rx) .
- More ray-tracing simulations shall be done to guide the system design and verify the system performance in realistic channels.