The 60 GHz In-Cabin Channel

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Abstract

- This contribution introduces the 60 GHz in-cabin environment and presents a preliminary characterization at 60 GHz. Based on real-time multi-antenna wideband measurement campaigns performed within an Airbus-340 aircraft cabin [1],[2], and using redundant cell configurations and different antenna arrays [3],[4], the in-cabin channel is characterized. The channel modeling/analysis to be addressed for the in-cabin environment will be useful for planning purposes [5] and for the applicability of system enhancement techniques.

Introduction

Public transportation usage models (I) - In-Flight applications

- 60 GHz systems are recently targeted as a Giga-bit short solution for broadband and low-interference WLAN backbone and in-cabin/car systems [7],[8], being part of the scenarios considered in a BMBF project in Germany [9], and included within the usage models for distribution of HDTV and rapid Upload/Download (i.e., usage models for intra-large-vehicle – 2c, and cars – 3d, 3e [10]) and VHT environments [10]. These public transport environments differ from the currently prioritized usage models [10],[11], i.e., top-3 related to marked volume (1c, 3a, 1b), and top-3 related to market timing (2b, 2a, 3e).

Public transportation usage models (II)

- In-Flight applications (from [10], remarks in blue)

Pre-Conditions:

Development of a low-interference and broadband WLAN backbone for passenger in-flight entertainment (IFE) applications and crew in-flight applications.

Application:

e.g. In-flight infotainment: Movies and TV channels available for on-demand viewing by 300 people. Each user controls their own application. Video being displayed is something like standard definition MPEG2 compressed.

Video requirements are: ~5Mbps, jitter is <200 msec, delay is < 200msec, 1.0E-4 PER. Aggregate bandwidth requirement is 300*5Mbps=1.5Gbps distributed by few access-points. Point-to-multi point system.

e.g. Content-download to local storage device: Data-rate needed: 1Gbit/s. Point-to-multi point system in multicast style operation.

Environment:

Metal narrow structure such as a bus or plane. Limited number of thin walls need to be penetrated, but many people and seats will cause some level of interference.

Traffic Conditions:

In addition to the video traffic, Data transfers consuming up to 20% of the total bandwidth, many additional video streams, and wireless display/controllers from a video game machine may be occurring during this use case.

Use Case:

1.User looks up a service on electronic device.
2.User selects a service (e.g. video-on-demand)
3.Compressed Video (e.g. ~5Mbps) is delivered to the individual for a period of two hours or quickly downloaded.
4.User may pause video during 2 hour period then resume watching.
5.Task is complete when user stops using the service.
6. Seamless handover between access-points necessary to avoid LOS-blockage.

Motivation: What is different for WLAN channel modeling?

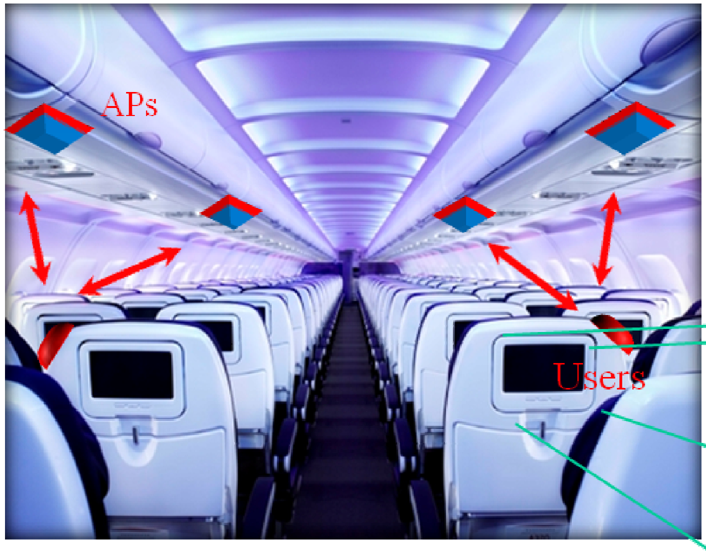
- The public transportation environments differ from the TGad proposed environments [12] because of the higher density of users, human behavior and usual metal cabins (also for trains, ships, buses, etc.). Moreover, the time-variant shadowing by human bodies (SHB) [13] is one of the most harmful propagation effects as it was verified in [2].
- Dual-polarization, power-control, macro-diversity and beamforming can be considered as system enhancements for 60 GHz IFE systems. Some of these techniques (i.e., beamforming and polarization) have been already considered within the TGad channel model proposal [6].
- These enhancement techniques can be characterized based on a real-time 60GHz-UWB-Multiantenna channel sounder, which finally can be used for refining a time-varying channel model.

The 60 GHz In-Cabin Channel

60 GHz In-Cabin Environment (I)

- Objective: For a Airbus 340 cabin, characterize the coverage and the large-scale/small-scale radio channel parameters for different antenna configurations taking into account antenna patterns, polarization and if it is necessary the human influence.

60 GHz In-Cabin Environment (II)



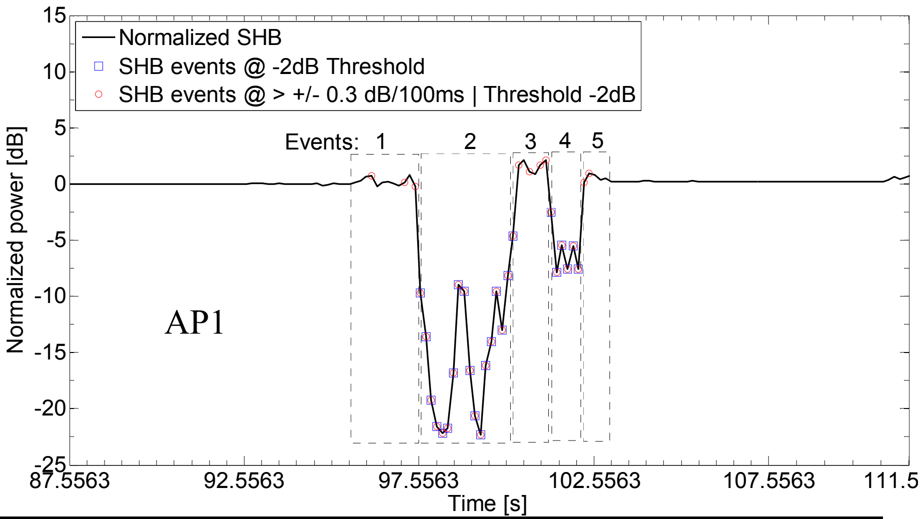
Human Events

- High shadowing margins
- High fading rate
- Long deep durations
- New in-cabin channel!!

HD IFE systems at millimeter-waves

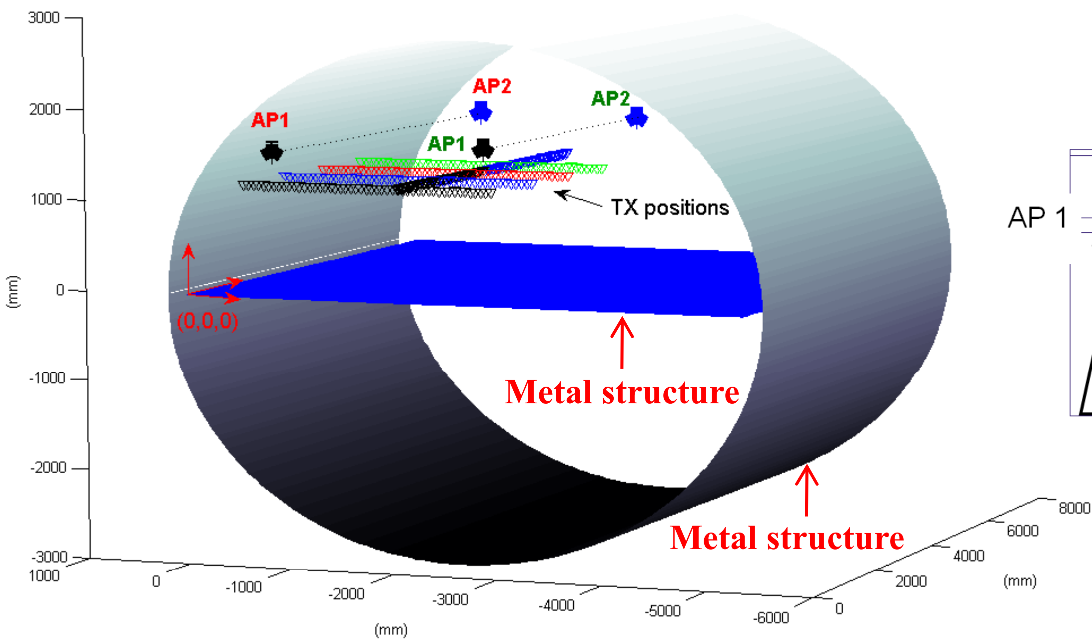
?

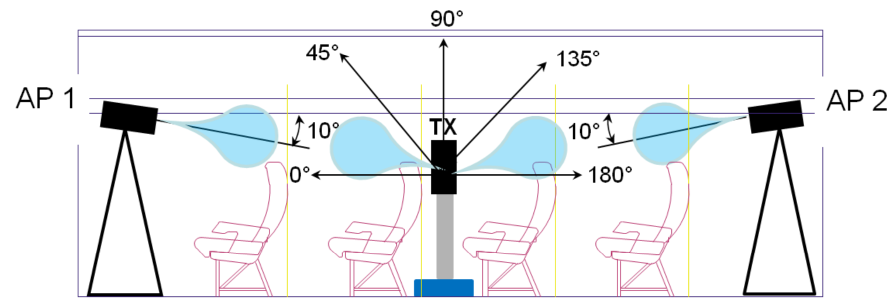
Macro-diversity, beamforming, power control, frequency reuse



60 GHz In-Cabin Environment (III)

- APs will be located close to the windows and at the middle of the cabin.
- The system should be a multi-cell system with a cell radius of at least 5 m.
- The system shall meet the applicable regulatory and safety requirements for passenger aircraft and for wireless communications in all countries of operation (e.g. use the 57GHz to 64GHz frequency-band and limit the output-power to 10dBm).





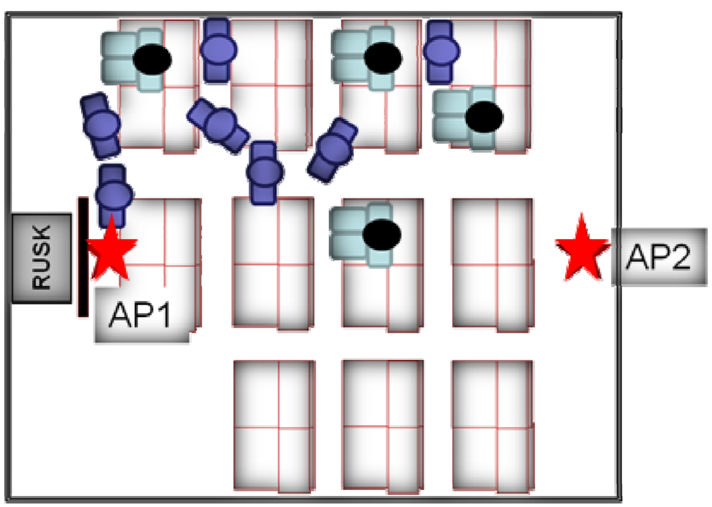
Lateral view and antenna tilts

60 GHz In-Cabin Environment (IV)

- Different human events can be considered for both AP configurations: passengers walking around, sitting, standing, and blocking the LOS, taking into account different amount of people.

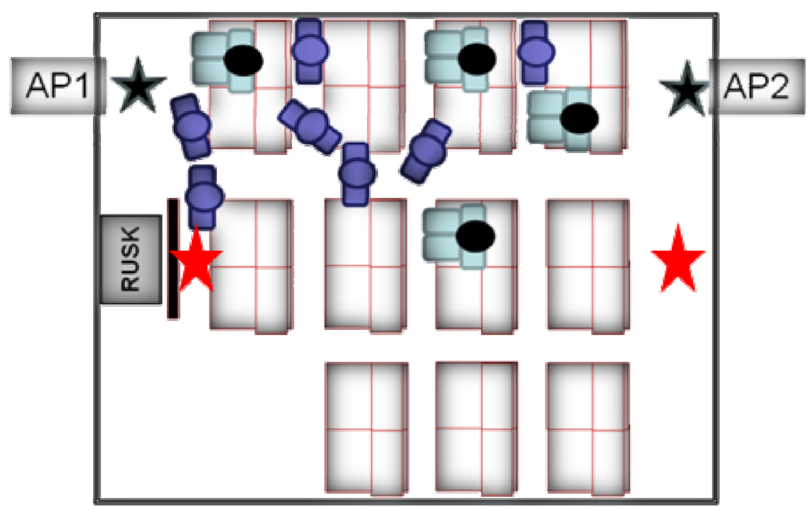
1

APs in the middle of the cabin



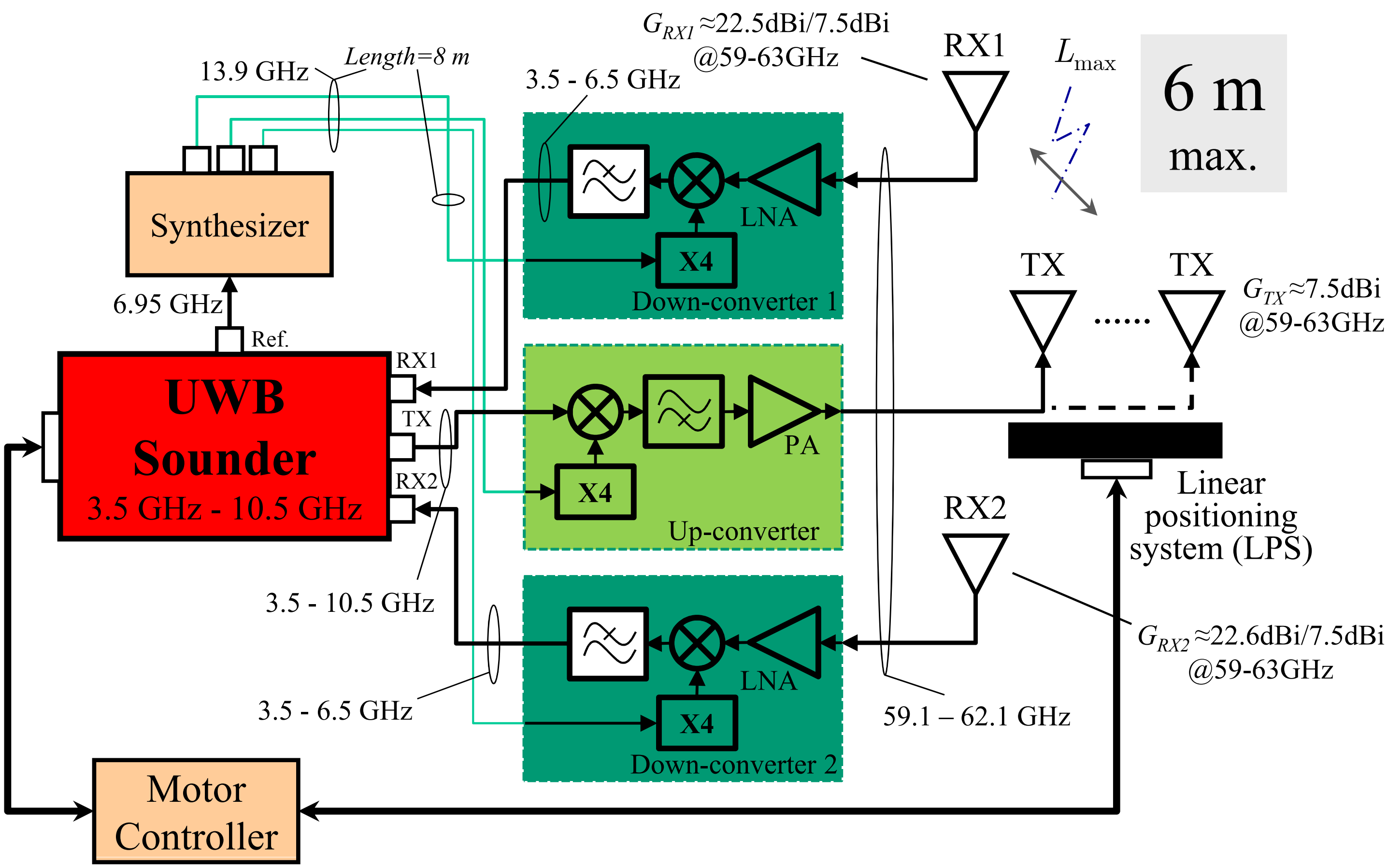
2

APs close to the windows



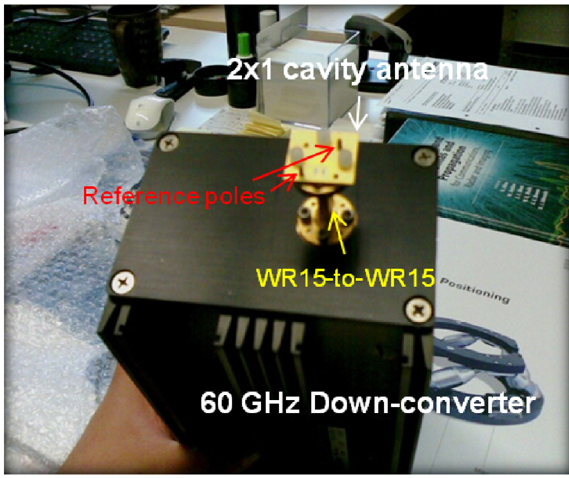
60 GHz In-Cabin Measurement Set-up (I)

- Real-time/multi-antenna 60GHz-UWB channel sounder.

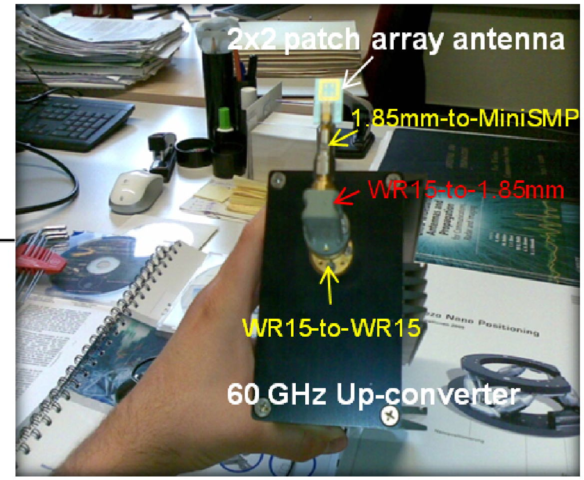


60 GHz In-Cabin Measurement Set-up (II)

- Real-time/multi-antenna 60GHz-UWB channel sounder.

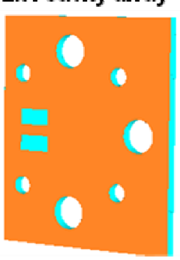


- RF: 59-62 GHz
- IF: 3.5-6.5 GHz
- LO: 14 GHZ
- 1 TX / 2 RX
- 40 dB dynam. r.



LTCC technology [3],[4]

2x1 cavity array

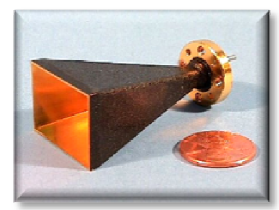


2x2 patch array

Available market technology

Waveguide WR15

Horn Antenna



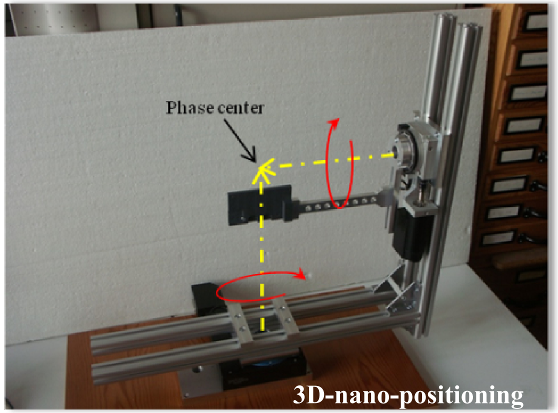
cavity_{AP1}-cavity_{TX}-cavity_{AP2}
cavity_{AP1}-patch_{TX}-cavity_{AP2}

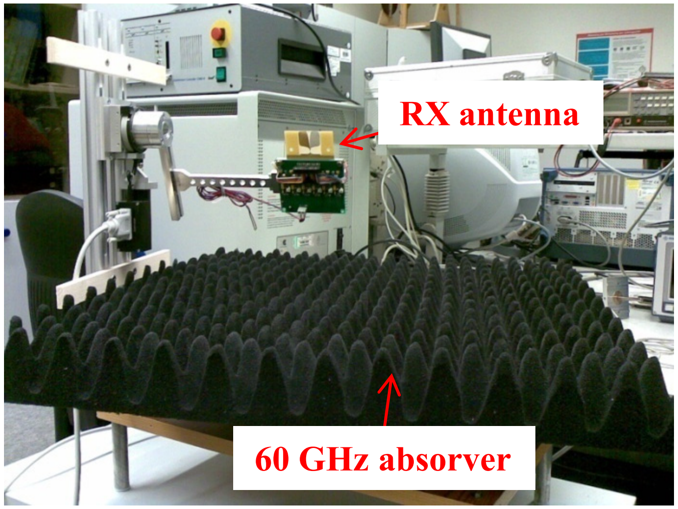
horn_{AP1}-waveguide_{TX}-horn_{AP2}
waveguide_{AP1}-waveguide_{TX}-waveguide_{AP2}

60 GHz In-Cabin Measurement Set-up (III)

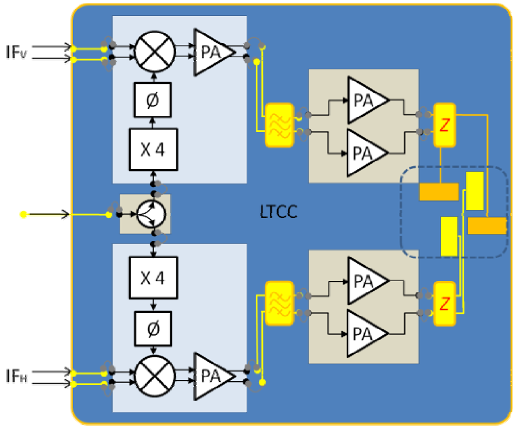
- Real-time/multi-antenna 60GHz-UWB channel sounder.

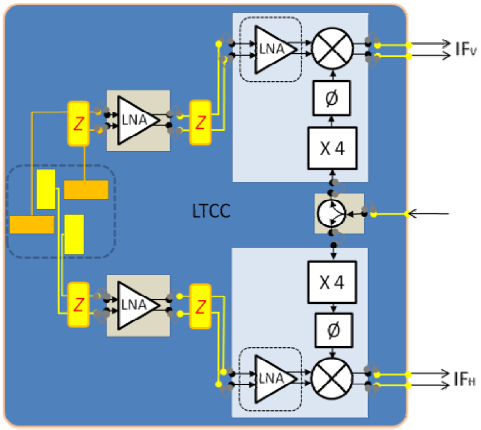
DoD/DoA measurements





Dual-polarization: dual channel chips (SiGe and GaAs), and dual-pol antennas

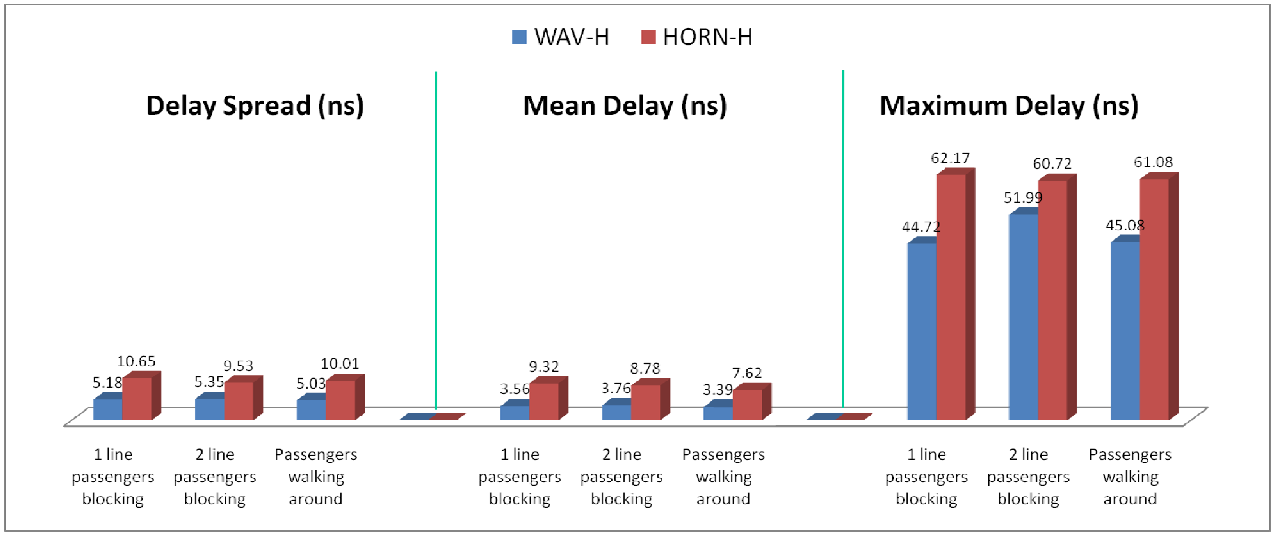




Preliminary In-Cabin Channel Analysis (I)

Median
Time Dispersion
20dB threshold

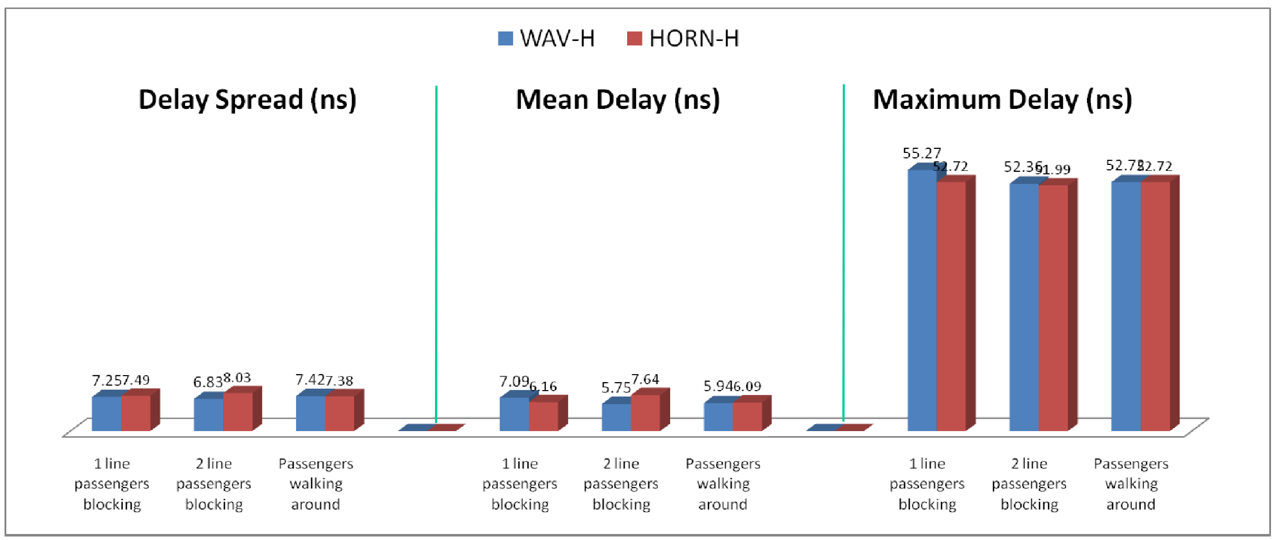
AP 1



1

APs in the middle of the cabin

AP 2



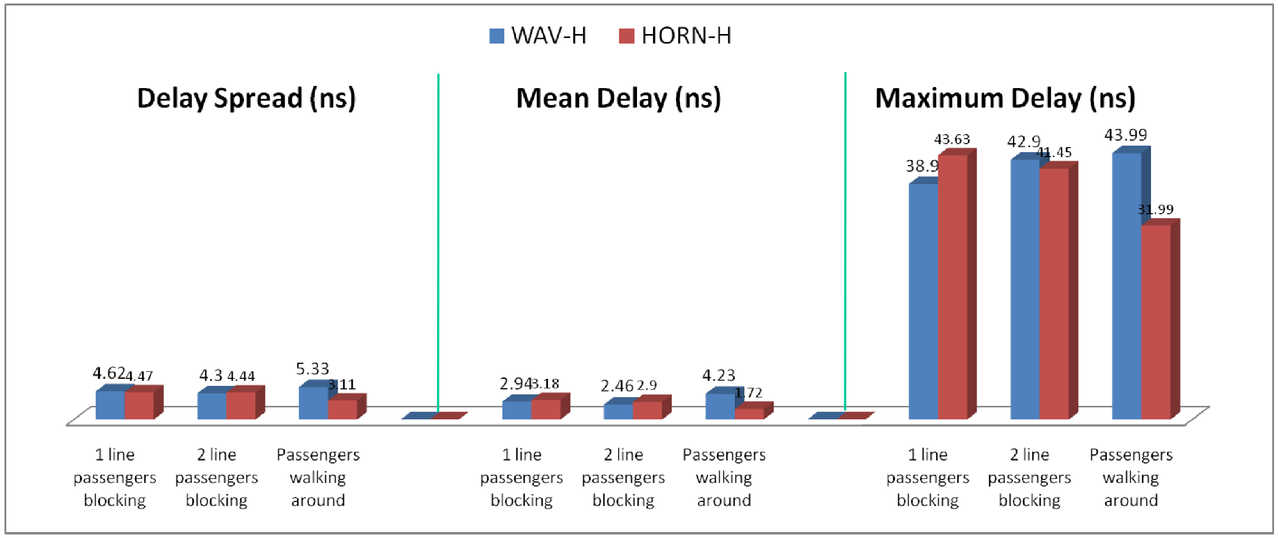
Preliminary In-Cabin Channel Analysis (II)

Median

Time Dispersion

20dB threshold

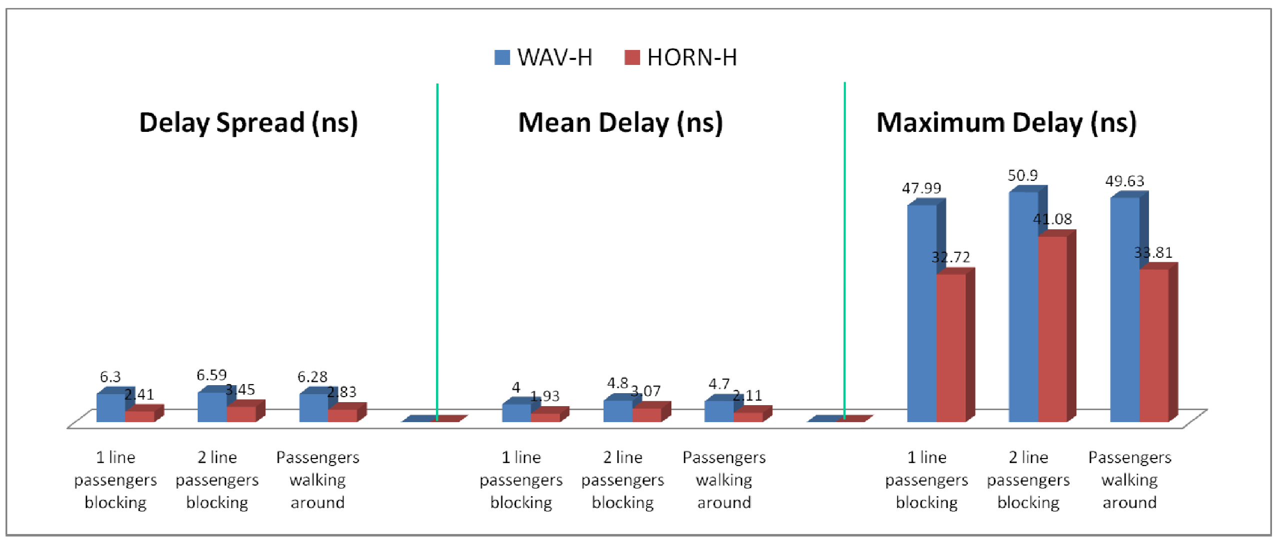
AP 1



2

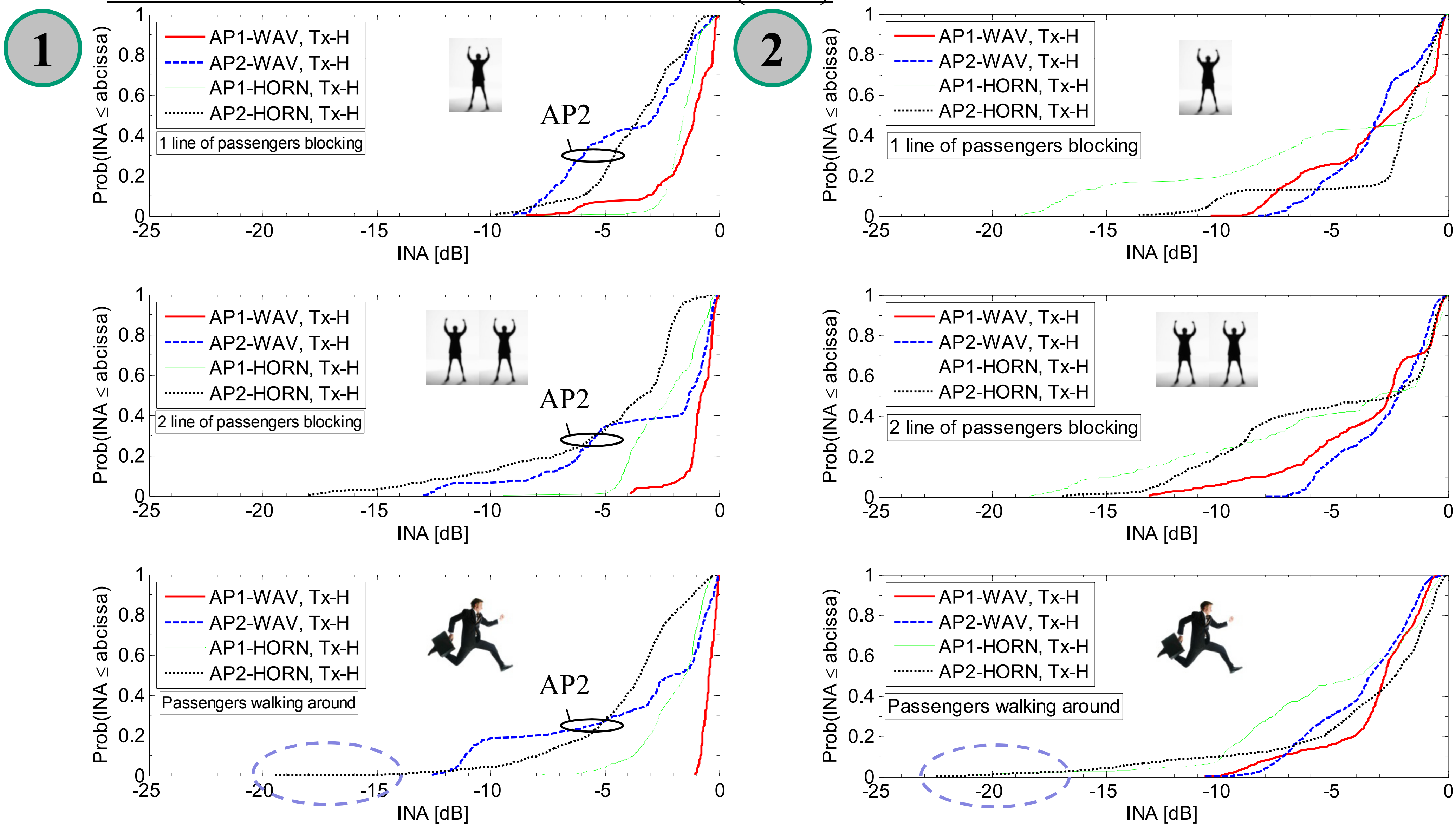
APs close to the windows

AP 2



Preliminary In-Cabin Channel Analysis (III)

Instantaneous normalized attenuation (INA)

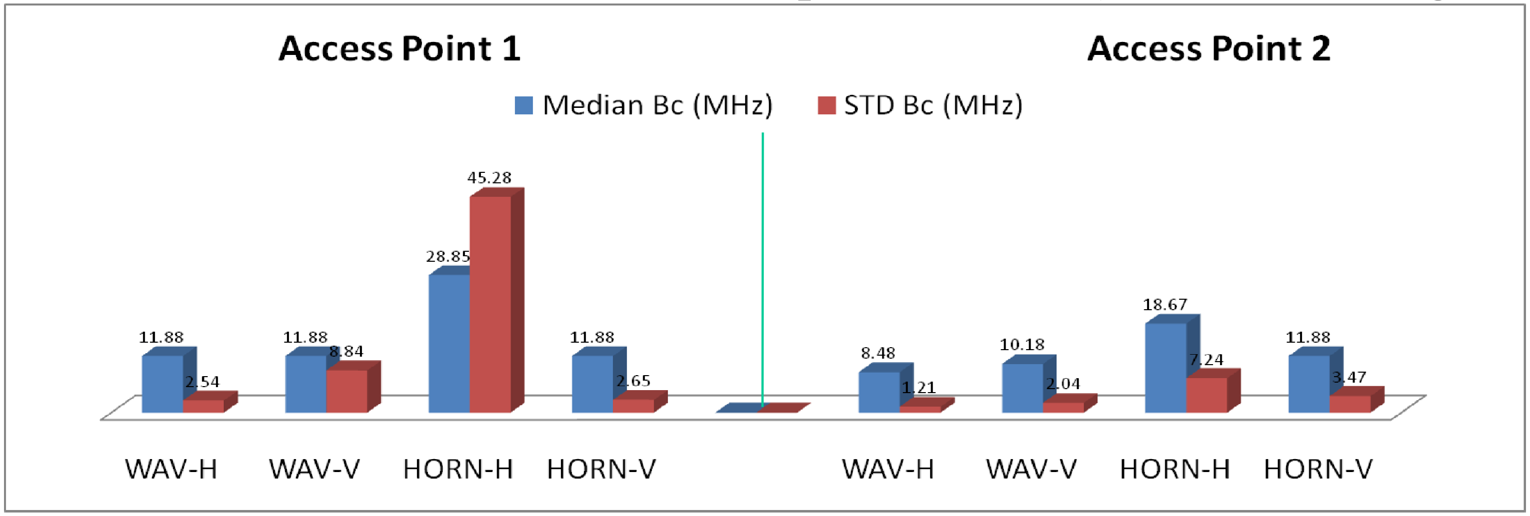


Preliminary In-Cabin Channel Analysis (IV)

Median/STD coherent bandwidth for V and H polarizations (1 seat row, 2m@2mm res.)

Static channel

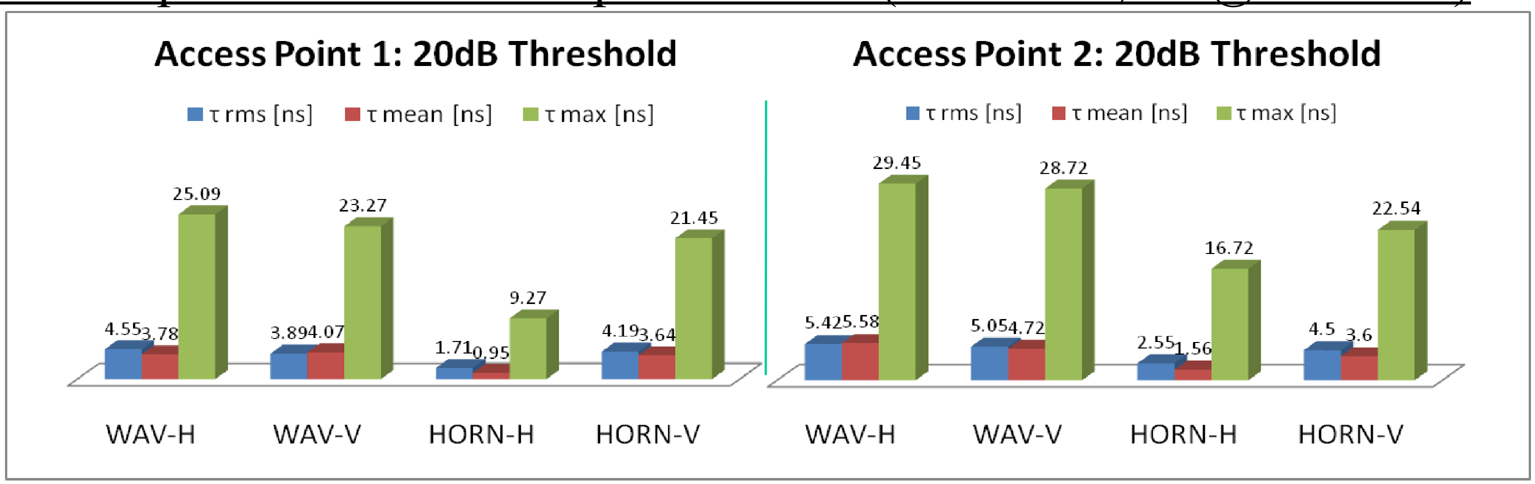
2



Median time dispersion for V and H polarizations (1 seat row, 2m@2mm res.)

Static channel

2



Preliminary In-Cabin Channel Analysis (V)

Shadowing link margins

	Reliability		
Antenna	**50 %**	**90 %**	**99 %**
WAVeguides (~7.5 dBi)	7 dB	11 dB	13 dB
HORNs (~22.6 dBi)	7 dB	17 dB	20 dB

- Higher antenna gains (horns) → good link budget only in LOS

Small-scale fading

Antenna	Mean fading
WAVeguides (~7.5 dBi)	~2.5 dB
HORNs (~22.6 dBi)	~5 dB

- Power variations→ 2 ns spikes.

Delay spread, maximum delays and polarization

Condition	Delay Spread Thresholds of 20 and 30 dB	Maximum delay Thresholds of 20 and 30 dB
Static	< 10 ns	< 100 ns
Human events	< 15 ns	< 100 ns

- Lower antenna gains (waveguides) & H → Highest delay.
- Higher antenna gains (horns) & H → Lower delay.
- Longer distances → Highest delay.

Coherent Bandwidths: $Bc_{0.9}$

Range (WAV and HORN)	HORN	WAV
~8-250 MHz	<250 MHz	<100 MHz

- Gap between chairs→ ↕ ~10 MHz.
- Main antenna lobe → ↑ ~250 MHz.
- Windows →↑~100MHz.
- Higher gains (horns) & H→↑$Bc_{0.9}$.

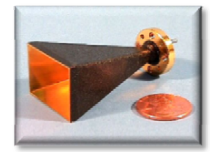
Higher antenna gains → higher shadowing by human bodies and higher small-scale fading.
Moderate antenna gains → good for link budget for obstructed-LOS (O-LOS).

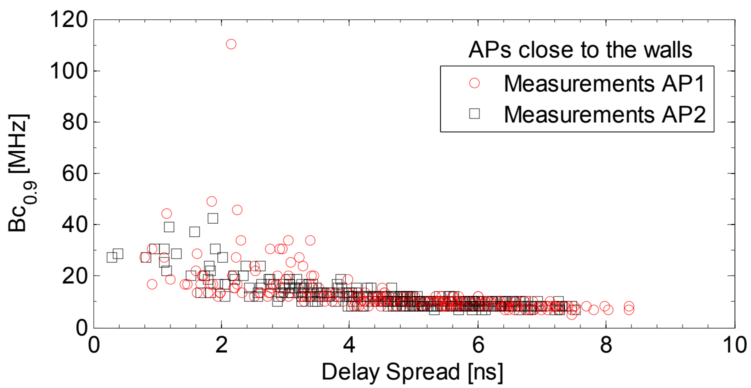
Preliminary In-Cabin Channel Analysis (VI)

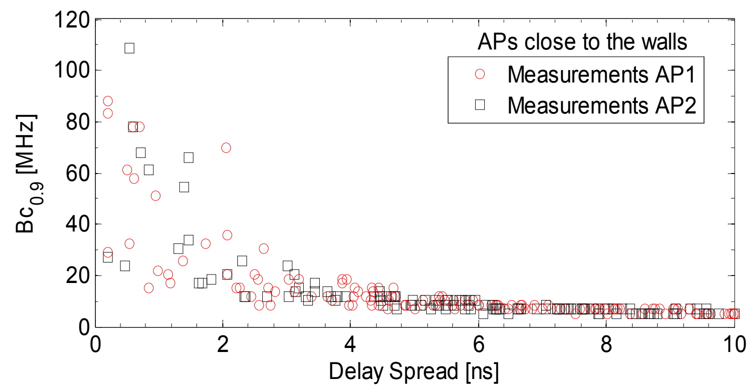
- Static channel measurements in 2

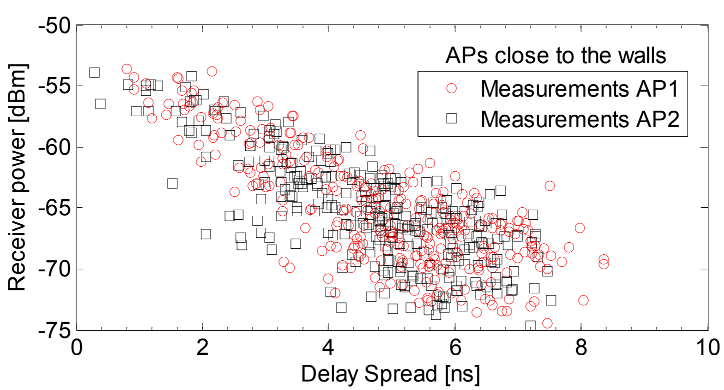
Waveguide WR15

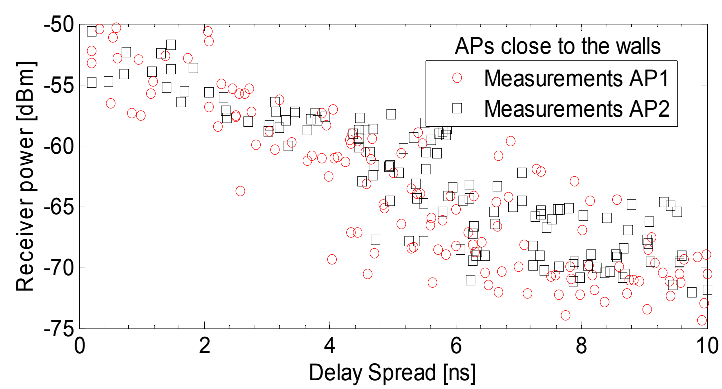
Horn Antenna







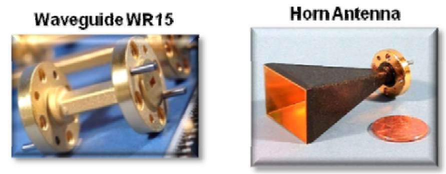




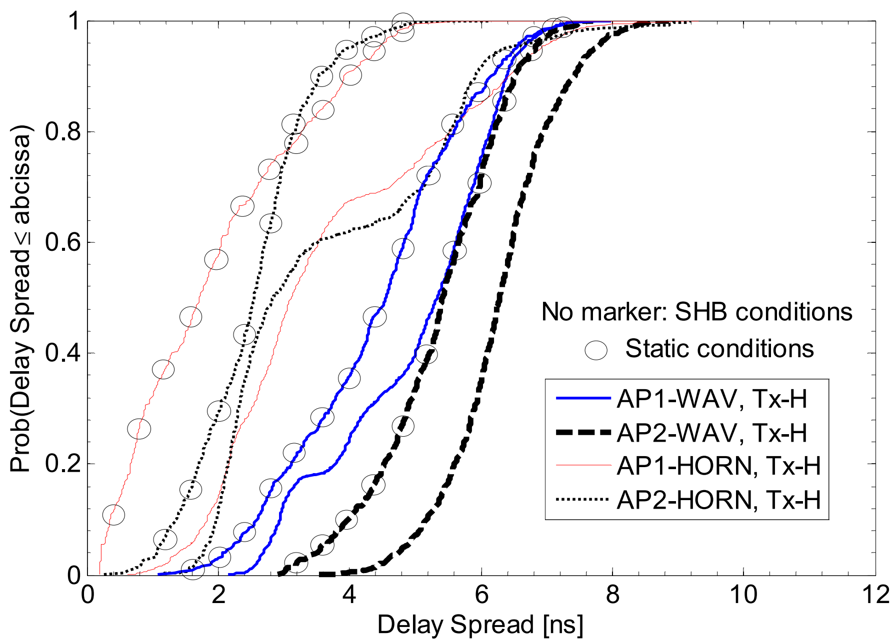
Preliminary In-Cabin Channel Analysis (VII)

- Dynamic channel measurements in 2

Available market technology

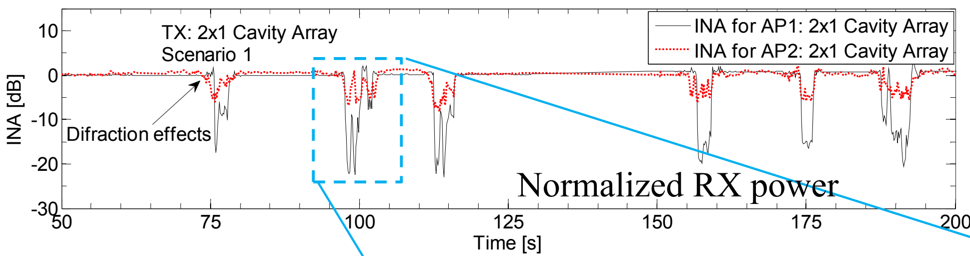


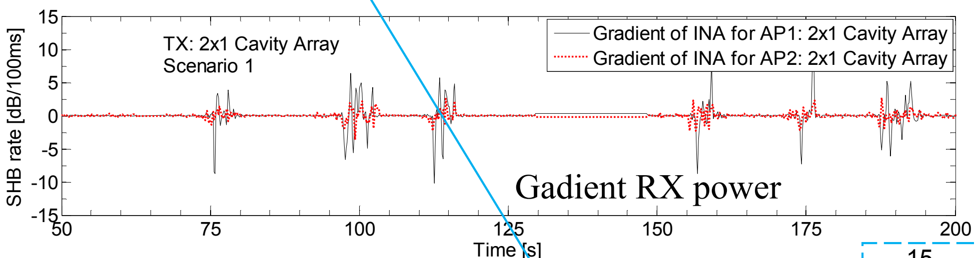
$horn_{AP1}$-$waveguide_{TX}$-$horn_{AP2}$
$waveguide_{AP1}$-$waveguide_{TX}$-$waveguide_{AP2}$



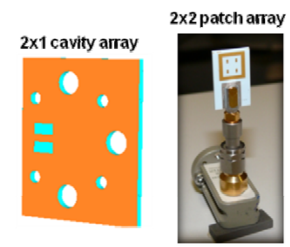
Preliminary In-Cabin Channel Analysis (VIII)

- Dynamic channel measurements



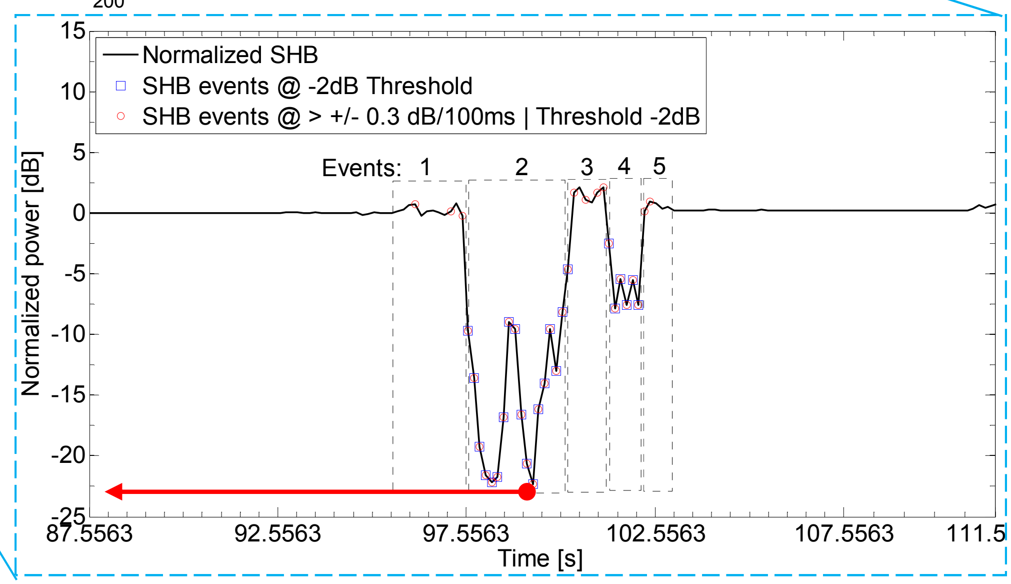


LTCC technology [3],[4]



cavity_{AP1}-cavity_{TX}-cavity_{AP2}

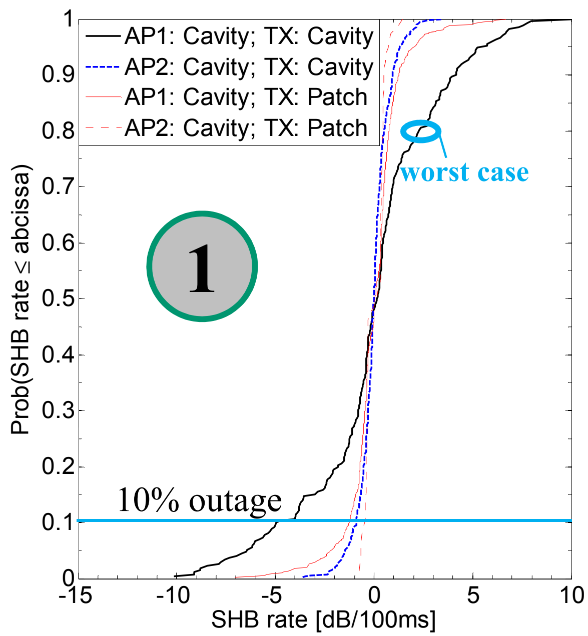
cavity_{AP1}-patch_{TX}-cavity_{AP2}

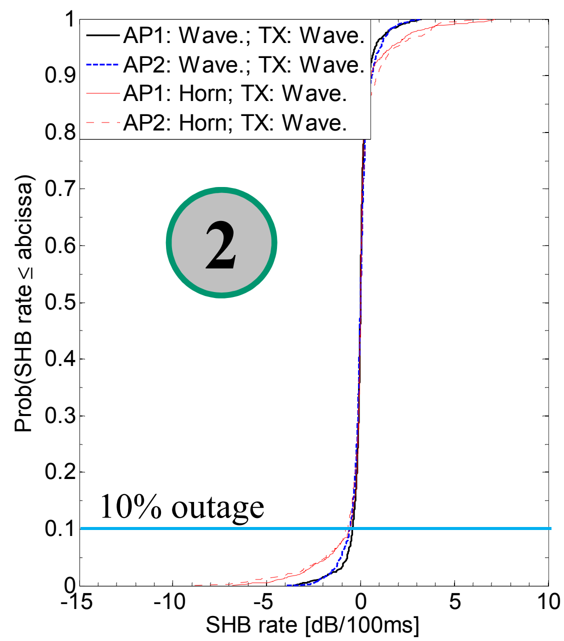


- Small Fresnel zones at 60 GHz
- Short oscillations +/- → diffraction
- Long deep fading → O-LOS
- High fading rate → dB/ms
- Skin reflections and body absorption

Preliminary In-Cabin Channel Analysis (IX)

- Dynamic channel measurements





SHB coherence time (AP1 and AP2)

Scenario 1	Scenario 2
cavity$_{AP1}$-cavity$_{TX}$-cavity$_{AP2}$	**waveguide$_{AP1}$-waveguide$_{TX}$-waveguide$_{AP1}$**
155.7 ms / 467 ms	311.3 ms / 311.3 ms
cavity$_{AP1}$-patch$_{TX}$-cavity$_{AP2}$	**horn$_{AP1}$-waveguide$_{TX}$-horn$_{AP2}$**
158 ms / 112.3 ms	155.9 ms / 1.089 s

Power control, beamforming, buffers

SHB cross-correlation AP1-AP2

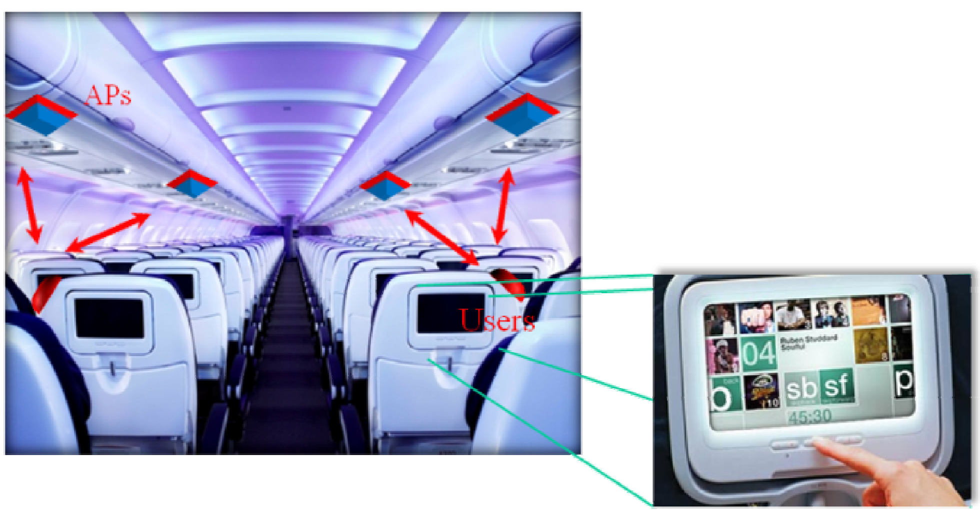
Scenario 1	Scenario 2
cavity$_{AP1}$-cavity$_{TX}$-cavity$_{AP2}$	**waveguide$_{AP1}$-waveguide$_{TX}$-waveguide$_{AP1}$**
0.6698	0.1602
cavity$_{AP1}$-patch$_{TX}$-cavity$_{AP2}$	**horn$_{AP1}$-waveguide$_{TX}$-horn$_{AP2}$**
0.3700	0.0154

In-cabin macro-diversity

Open Issues

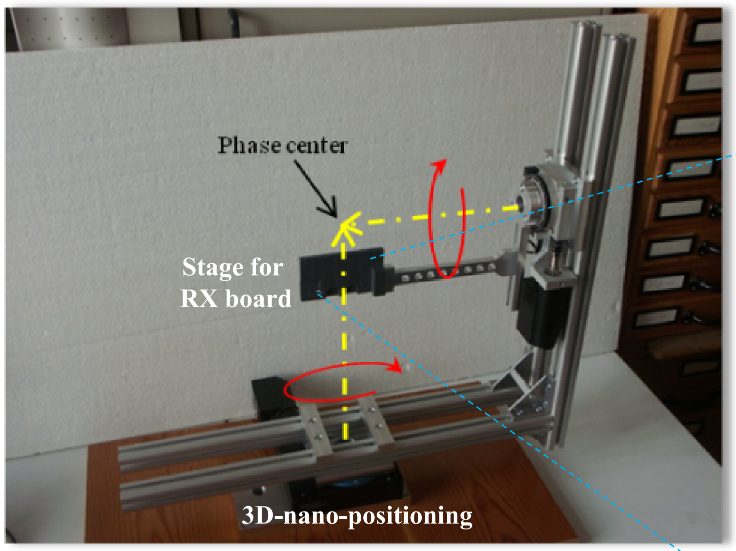
Plans for channel modeling (I)
- Follow IEEE 802.11ad channel model requirements

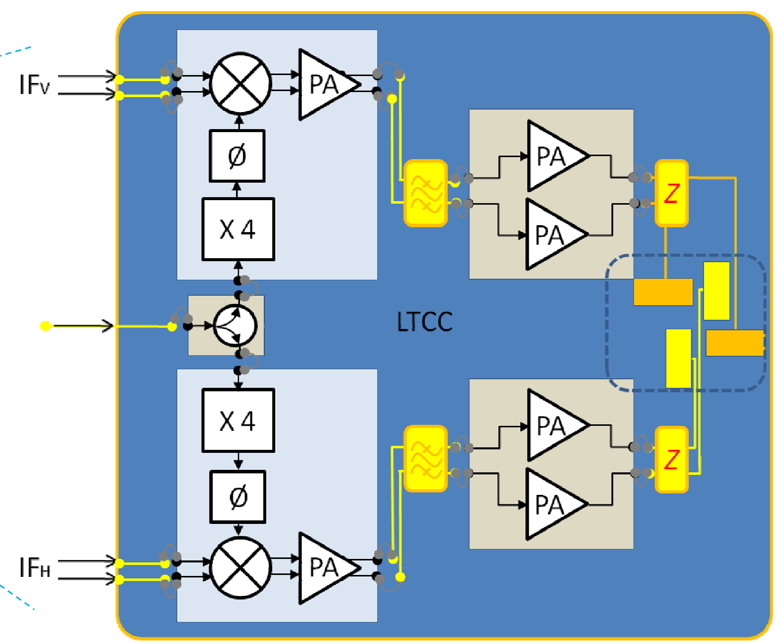
- Channel measurements and modeling for Usage Model 2c (in-cabin) following [6]:
  - Static LOS channel
  - Inter cluster parameters
  - Intra cluster parameters
  - Polarization impact
  - Path loss modeling



Plans for channel modeling (II)
- Follow IEEE 802.11ad channel model requirements

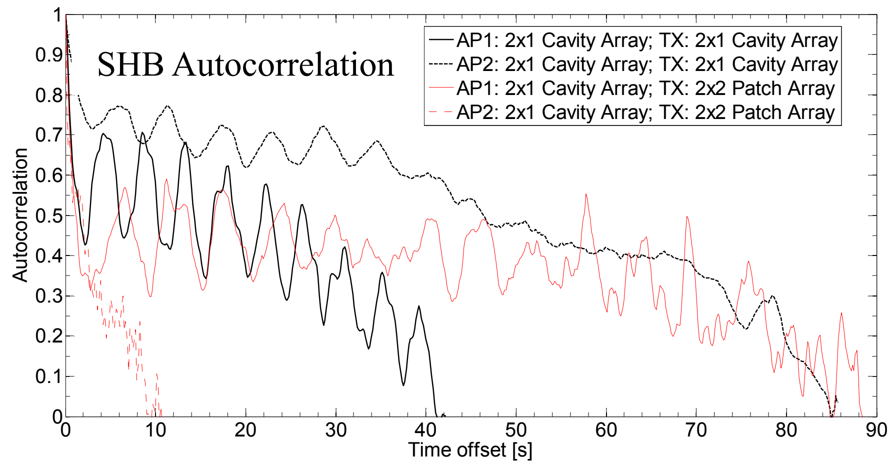
- DoD/DoA measurements
- Dual-polarization: dual channel chips (SiGe and GaAs), and dual-polarized antennas



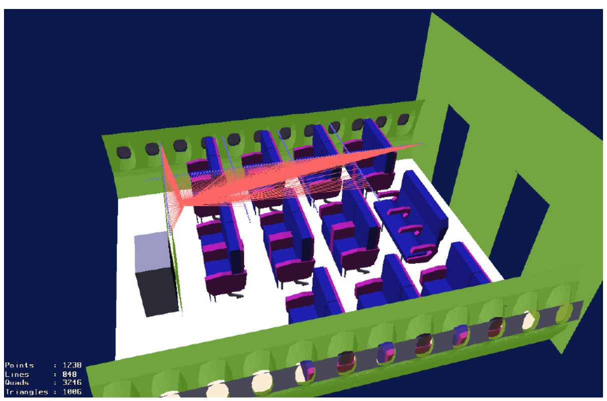


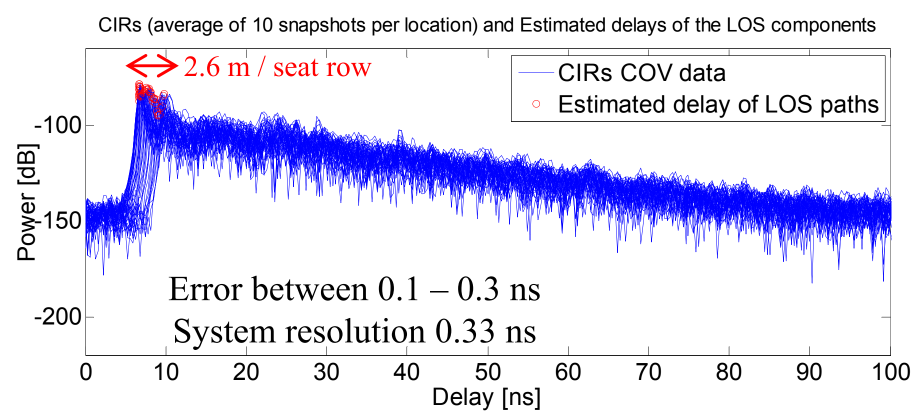
Plans for channel modeling (III)
- New enhancements in channel model

- Diversity analysis – time-varying shadowing statistics: SHB deep, duration, rate, auto-correlation and cross-correlation



- Ray tracing





Plans for channel modeling (IV)
- Optional live-meeting-room environment

- Diversity analysis – time-varying shadowing statistics: SHB deep, duration, rate, auto-correlation and cross-correlation


Plans for channel modeling (V)

- 1x2 real-time/multi-antenna channel measurements with 3 GHz bandwidth for the in-cabin environment
- In-cabin static and dynamic channel analysis, e.g, path loss with time-varying shadowing due to human bodies
- Macro-diversity analysis for in-cabin system enhancement (under preparation)
- In-cabin angular analysis by ray-tracing simulations (under preparation)
- In-cabin DoD/DoA measurements (under preparation)
- Coherent dual-polarized channel measurements (under preparation)
- Live meeting room environment (data available)

Conclusions

- Low-interference and broadband in-flight and in-car infotainment systems are a potential market for 60 GHz systems and the industrial interest is already on that way.
- SHB is one of the most harmful effects for 60 GHz HD-Infotainment systems.
- The SHB is higher for high antenna gains and different between distributed APs, which requires space-time correlation analysis.
- Real-time/multi-antenna 60GHz-UWB channel sounders allow dynamic analysis, auto-correlation and cross-correlation analysis of SHB.
- The shadowing link margin should be at least 11/17 dB for moderate/high directivity antennas for 90% coverage.
- The delay spread increases with human events.
- It was found from distributions that the delay spread is always lower than 10 ns for all configurations using thresholds of 20 or 30 dB in static conditions. If human events are included, the delay spread grows up to about 15 ns in some cases.
- The delay spread is lower than the usual for indoor environments.
- Coherent bandwidths between 8 and 250 MHz have been found.

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