mmMAGIC

Research Findings on mm-wave Technology and Spectrum – Mobility Aspect

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Introduction

- Support for mobility is an essential component in cellular.
- Sub-6 GHz systems provide coverage through omni or wide angled sectors with larger area. Supporting mobility is relatively easy.
- Mm-wave systems need to employ directional beamforming to counter the higher path loss. Makes mobility support more challenging.
- Several other factors also influence mobility in higher frequencies.

Analysis approach – FoM development

- We develop a Figure of Merit (0 to10) for the different bands in mm-wave spectrum, for their ability to support mobility.
- 6 GHz is taken as the reference frequency, with an FoM=10.
- Many variables are influencing mm-wave system design. We develop two distinct strands to simplify the analysis.
  - Strand 1 -Fix the system bandwidth across the 6-100 GHz, and vary the antenna numbers in AP and UE to achieve the coverage and capacity targets.
  - Strand 2- Fix the antenna numbers (to a reference number, like 32) and vary the system bandwidth, to achieve the coverage and capacity targets.

Quantifying Tracking Accuracy

- Tracking Accuracy (TA) refers to the challenge of tracking mobile user(s) with narrow beam transmissions. When increased path loss is compensated with higher antenna gain (strand 1), this challenge increases with carrier freq.
- Relying on the path loss relationship to the square of frequency and N_H, N_V antennas needed to combat path loss: $20log\frac{f_{max}}{f_{min}} = 10log\frac{(N_H N_V)_{max}}{(N_H N_V)_{min}}$
- The TA is simplistically assumed to relate linearly to the 3dB beam-widths in H and V planes. The beamwidths are again related to the number of antennas:
$$\frac{(TA)_{max}}{(TA)_{min}} = \frac{(N_H N_V)_{max}}{(N_H N_V)_{min}} = \left(\frac{f_{max}}{f_{min}}\right)^2$$
- Considering f_{min} as the reference freq=6 GHz, the TA can be quantified as a Mark_{TA}:
$$Mark_{TA} = MarkRef_{TA} - m_{TA} \cdot log\left(\frac{f}{f_{ref}}\right)^2$$

Quantifying the Doppler Impact

- Nominally, the Doppler shift (f_D) increases linearly with the frequency, making it an important factor in mm-wave mobility: $f_D = f_c . \frac{v}{c}$
- Doppler spread has a U shaped distribution from [-f_D to f_D], with the simplistic case of the mobile user getting signal paths from 360^o (omni) angular widths. A more detailed analysis on narrower widths was conducted later and reported in slides 10-12.
- In multi-carrier systems, sub-carrier spacing can be tuned to accommodate the max Doppler spread, more flexibility in Strand 2.
- The impact of Doppler shift/spread can be accounted for by and index value $Mark_D$, as: $Mark_D = MarkRef_D - m_D \cdot log\left(\frac{f}{f_{ref}}\right)$

Quantifying Coherence Time Impact

- Coherence time (T_c) defines the interval when the channel variations are limited to an acceptable threshold. Smaller coherence times need more frequent CSI updates – hence more system overhead.
- T_c can be simplistically related to Doppler shift as; $T_c \sim \frac{1}{f_D}$
- As before, a linear relationship can be drawn for the impact of T_c . Hence the index value Mark_{coh} would be:

$$Mark_{Coh} = MarkRef_{Coh} - m_{Coh} \cdot log\left(\frac{f}{f_{ref}}\right)$$

Overall Impact on Mobility

- The 3 factors presented above can be combined, with m representing an overall index: $Mark = Mark_{TA} + Mark_{D} + Mark_{Coh} = MarkRef - m \cdot log\left(\frac{f}{f_{ref}}\right)$
- Composition of m depends on the analysis strand. For strand 1 (fixed BW) $m|_{BW}$ is defined as: $m|_{BW} \equiv 2m_{TA} + m_{D} + m_{Coh}$
  The factor 2 in m_{TA} is taken as the TA related to the square of the freq. ratio.
- For Strand 2 (fixed antenna numbers), the TA is constant across the freq. range. $m|_{no.antennas} \equiv m_{D} + m_{Coh}$
- Considering the severity and the novelty of the challenges, the values of m_{TA}=2, m_{D}=1 and m_{coh}=1 are assigned.

Numerical FoM Derivations

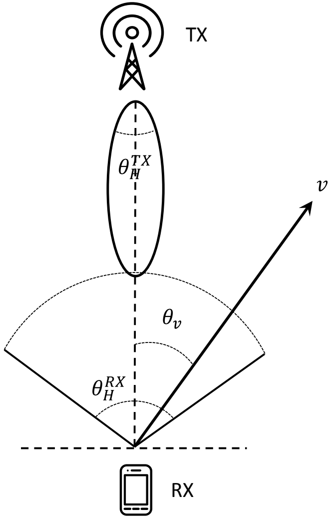
- For strand 1 – fixed BW and antenna numbers increased with $(f_c/f_{min})^2$:

Carrier frq (GHz)	6 (f_{ref})	28	38	73
Figure of Merit	10	5.99	5.19	3.49

- For strand 2 – fixed number of antennas and the bandwidth increased as per the requirements posed by the capacity analysis (not reported here):

Carrier frq (GHz)	6 (f_{ref})	28	38	73
Figure of Merit	10	8.66	8.4	7.83

Further Analysis into Doppler Spread



- Classical Doppler spread analysis assumes that multi-path signal components are received by the UE from 360^{o} angles.
  - Doppler shift: $f_D = (v/c) f_c \cos(\theta - \theta_v)$
  - Doppler spread: U shaped as per Jakes formula
- However, mm-wave directional BF needs new analyses.
- A theoretical analysis is provided under the following criteria:
  - A - The receive beam width (bw) is comparable to the transmit bw. A single cluster of scatters will determine the Doppler effects.
  - B - The receive bw is much larger than the transmit bw. Multiple distinct clusters of scatters are available, and we assume uniformly distributed AoA within clusters.

Doppler shift and spread – Analytical formulae

- Under option A, simplified expressions can be derived for the Doppler shift and spread:

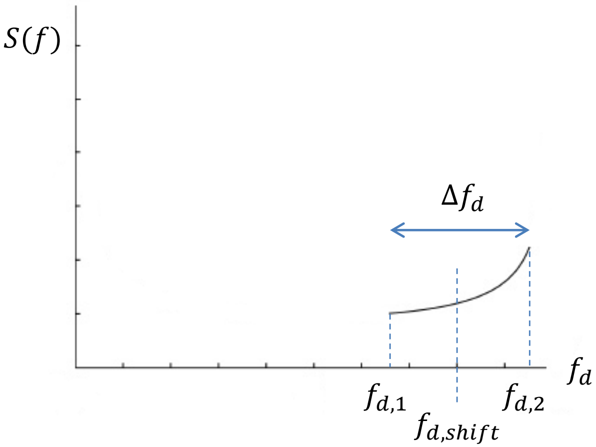
TABLE I
SUMMARY OF APPROXIMATE DOPPLER SHIFT AND DOPPLER SPREAD VALUES WHEN THE RECEIVE BEAM WIDTH IS SUFFICIENTLY SMALL

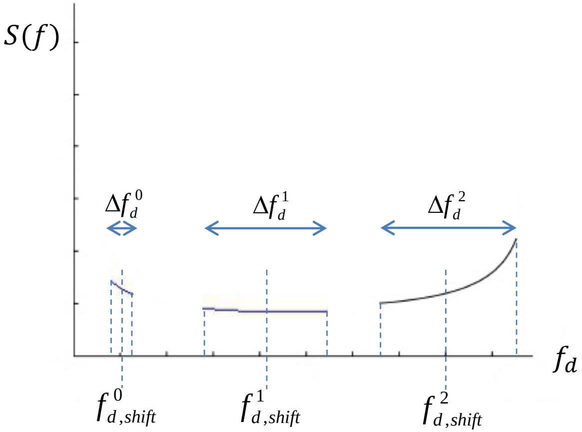
Angular region	Doppler shift	Doppler spread
$\lvert\theta_v\rvert \le \frac{\theta_H^{RX}}{2}$	$f_D\left(1-\frac{\theta_H^{RX}\lvert\theta_v\rvert}{4}\right)$	$f_D\frac{\theta_H^{RX}}{2}\lvert\theta_v\rvert$
$\frac{\theta_H^{RX}}{2} < \lvert\theta_v\rvert \le \pi - \frac{\theta_H^{RX}}{2}$	$f_D\cos\theta_v$	$f_D\theta_H^{RX}\lvert\sin\theta_v\rvert$
$\pi - \frac{\theta_H^{RX}}{2} < \lvert\theta_v\rvert \le \pi$	$-f_D\left(1-\frac{\theta_H^{RX}\lvert\pi-\theta_v\rvert}{4}\right)$	$f_D\frac{\theta_H^{RX}}{2}\lvert\pi-\theta_v\rvert$

- Three angular regions for θ_v (user direction of motion) is considered to simplify the expressions.
- Interestingly, the Doppler spread has become a function of θ_H^{Rx}, which can be controlled with the number of UE antennas – can keep the Doppler spread constant with increasing freq. and velocity, esp. for high speed routes (railways, motorways).

Modified Doppler Power Spectrum

- Option A – comparable Tx, Rx bw, only one prominent cluster of multi-path.
- Option B- Rx bw is much larger than Tx bw, few dominant clusters of mulit-path.





Conclusions

- Mobility will be one of the key challenges that need to be addressed by 5G mm-wave systems.
- mmMAGIC project has analysed challenges arising from mobility and quantified FoM values for different bands of mm-wave spectrum.
- Generally for high freq mm-wave spectrum, mobility presents greater challenges, in both fixed BW and fixed antenna number systems.
- The Doppler effects were further analysed in the project, leading to simple, approximated derivations, which can lead to effective solutions.

THANK YOU!

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