A Comparison of 24 GHz and 2.55 GHz MIMO Measurements in Two Indoor Scenarios

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***Abstract*—MIMO measurements at 24 GHz and 2.55 GHz are compared for two buildings consisting of classrooms and offices on two college campuses. The results indicate that mutual information for $4{\times}4$ MIMO with 15 dB SNR is very similar, suggesting similar multipath structure for the two different bands. Path loss is approximately 30 dB higher at 24 GHz, mainly due to the reduced receive aperture at the higher frequency. These results suggest that 24 GHz may be a suitable replacement for near and medium range indoor wireless applications currently using the 2.4 GHz ISM band.**

I. Introduction

The widening gap between data transmission rates for wired and wireless networks has generated interest in using millimeter-wave (mm-wave) bands (30-300 GHz) to support gigabit wireless [1], with most attention focused at and above 60 GHz. However, employing these bands to host services currently offered in the UHF band is challenging – due to the higher material losses and directional nature of mm-wave channels – and therefore attention has turned to upper microwave bands that provide increased bandwidth with more favorable propagation conditions. This work characterizes indoor propagation at 24 GHz in the Clyde Building at Brigham Young University (BYU) and the Acopian Engineering Center at Lafayette College (LC) and compares the results with those from co-located measurements at 2.55 GHz.

II. Measurement Setup

The prototype BYU 24 GHz $4{\times}4$ multiple-input multiple-output (MIMO) channel sounder was presented previously in [2], and a similar system was developed at LC, as depicted in Fig. 1. Unlike the BYU system that employs a chirp for probing, the simpler Lafayette system uses a single tone in order to investigate the spatial nature of 24 GHz channels. A microwave source at the transmitter generates a 12 GHz tone that is power amplified and fed to a SP8T switch. The signal from each switch output port is fed to an active frequency doubler, providing amplification and resulting in a 13 dBm tone at 24 GHz. The receive signal from each antenna is selectively fed to the common receiver chain using a SP8T switch. This signal is amplified by 45 dB, downconverted to 50 MHz, sampled at 100 MS/s (12 bits/sample), and stored on a PC. Switch synchronization is achieved using a common 10 MHz reference supplied by the transmit microwave source and fed to the receiver using a cable, and a complete $4{\times}4$ scan requires 0.84 ms. The 2.55 GHz sounders at BYU and LC are both switched architectures similar to that shown in [3]. Key parameters of the two measurement systems are given in Table I. All measurements use quarter-wave monopole antennas with $\lambda/2$ inter-element spacing, with the 24 GHz array depicted in Fig. 2.

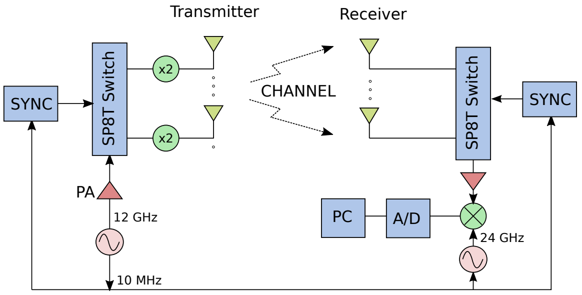

Fig. 1. Block diagram of the 24 GHz measurement system used at LC.

TABLE I
Channel Sounder Parameters

	24 GHz		2.55 GHz	
	BYU	LC	BYU	LC
Tx Signal	Chirp	CW	4 Tones	CW
Bandwidth	500 MHz	-	20 MHz	-
Tx Power	20 dBm	13 dBm	23 dBm	23 dBm
LNA	70 dB	45 dB	40 dB	40 dB
Synch.	Optical	Cable	Rubidium	Cable
Antennas	Monopole	Monopole	Monopole	Monopole
Array Size	4×4	4×4	8×8	8×8
Array Types	ULA	ULA	ULA	ULA
Snapshot	40 ms	0.84 ms	3.0 ms	3.0 ms

III. Results

In both the BYU and LC measurements, the transmit node was placed in a main hallway (simulating an access point), while the receiver assumed three location types: 1) line-of-sight (LOS) in the same hallway, 2) non-LOS (NLOS) around one or two corners in the

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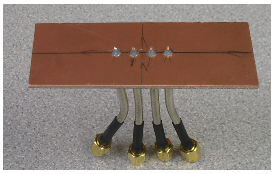

Fig. 2. Antenna arrays used for the 24 GHz BYU and LC measurements.

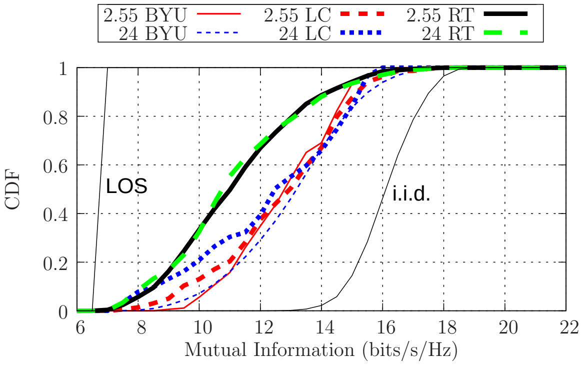

Fig. 3. Mutual Information CDFs comparing all data from BYU, LC, and ray tracing. Mutual information CDFs for idealized LOS (keyhole) and i.i.d. channels are also shown for comparison.

same hallway, or 3) NLOS in rooms connected to the hallway. Measurement results were compared to those from detailed ray-tracing (RT) simulations of each environment, where floor, ceiling, walls, and doors were modeled. Mutual information was computed assuming an uninformed transmitter according to

$$C = \frac{1}{N_F} \sum_{n=1}^{N_F} \log_2 \left| \mathbf{I} + \frac{\rho}{N_T} \mathbf{H}^{(n)} \mathbf{H}^{(n)H} \right|, \tag{1}$$

where N_F is the number of frequency samples, $N_T = 4$ is the number of transmitters, $\mathbf{H}^{(n)}$ is the normalized channel matrix measured at the nth frequency sample, ρ is the signal-to-noise ratio (SNR), and $| \cdot |$ is the determinant. A system employing transmit power control is assumed with $\rho = 15$ dB for all results.

Figure 3 shows the cumulative distribution function (CDF) of mutual information for the complete set of measurements, where equal weight is given to the three location types described above. At the 50% probability level, there is very little difference between the mutual information at 2.55 GHz and 24 GHz, and also little difference between the BYU and LC data. At a low outage level of 10%, the BYU data has nearly identical mutual information at 2.55 and 24 GHz (10 bits/s/Hz), while the LC data shows a difference at the two frequencies of only around 10%. This result emphasizes the remarkable similarity in statistical spatial properties at 2.55 and 24 GHz in the studied environments. Ray-tracing simulations exhibit between 0 and 2 bits/s/Hz lower mutual information than measurements, likely due to the simple model that does not include furniture or rough surface effects.

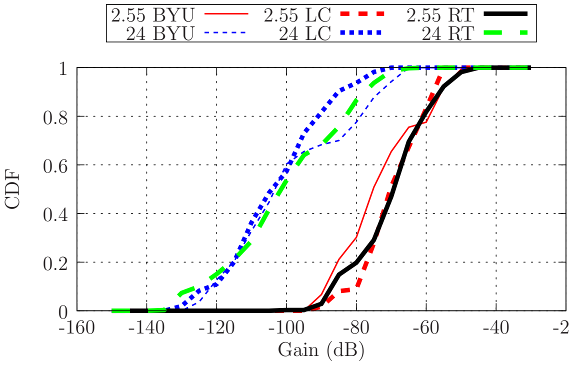

Fig. 4. Gain CDFs comparing all data from BYU, LC, and ray tracing.

Fig. 4 shows the channel gain (negative of path loss) for all BYU, LC, and RT data. The BYU data exhibits somewhat less loss at 24 GHz than the LC data, and the offset between the 2.55 and 24 GHz curves is approximately 30 dB at the 50% level. Furthermore, the results show that ray tracing gives a reasonable prediction of the path-loss CDF at both frequencies.

IV. CONCLUSION

This work compares 4×4 MIMO measurements at 24 and 2.55 GHz to assess the viability of using 24 GHz as a replacement for indoor wireless services currently in the UHF band. Measurements at BYU and LC both indicate that mutual information is remarkably similar at the two widely separated frequencies, suggesting that sufficient multipath is available at 24 GHz to support MIMO communications. The main drawback is the increased path loss (approximately 30 dB), which results largely from the smaller receive aperture at 24 GHz, and to a lesser degree from increased material losses. This study suggests that if the additional 30 dB of link loss can be tolerated, 24 GHz may be a simple replacement for NLOS applications at 2.4 GHz.

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