Efficiency Evaluation of MIMO OFDM Systems in On-Ship Beneath-Deck Environments

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Abstract- *Beneath-deck compartments on naval vessels furnish a difficult environment for wireless networks. The metal partitions of the compartments produce multiple reflections that can degrade integrity of signal. Between compartments, the metallic bulk-heads hinder the propagation of electromagnetic waves, limiting network connectivity. Orthogonal frequency-division multi-plexing (OFDM) is proposed to mitigate the consequences of inter symbol interference (ISI) prompted by a couple of reflections. Moreover, using a couple of antennas for channel range has shown to improve communications reliability and capacity. Single and multi antenna OFDM physical layers had been demonstrated inside a couple of under-deck areas aboard Thomas S. Gates (CG 51), a decommissioned Ticonderoga-classification US Navy cruiser. Measurements have been all for 4 OFDM-based schemes usual of present-generation Wireless Local Area Network (WLAN) technologies. The efficiency of multi antenna signaling systems, together with 2 x 2 Alamouti area-time coding and a couple of 2 more than one-input–multiple-output spatial multiplexing (MIMO- SM), have been compared to the performances of 1 2 maximal ratio combining (MRC) and a conventional single-input–single - output (SISO) approach. Results indicate that the tested MIMO systems can approximately double the channel potential. Throughput as excessive as 36 Mb/s was once completed in conventional circumstances the place SISO hyperlinks best admitted rates of 18 Mb/s.*

Keywords- Electromagnetically reflective spaces, multiple-input–multiple-output (MIMO), orthogonal frequency-division multiplexing (OFDM), shipboard propagation, software radio.

I. INTRODUCTION

For More than a decade, there has been increased curiosity in characterizing electromagnetic propagation in under–deck environments of naval vessels for the reason of deploying wireless networks. Under-deck spaces are predominantly metal structures. These spaces constitute multipath wealthy environments that introduce distinct challenges for deploying wireless networks [1]. The RF Spectrum on ships additionally introduces lively radar and verbal exchange alerts, emissions from working machinery, and interference through personnel on board[1]. Still, deploying wireless networks in below-deck spaces is desirable as it presents big potential in augmenting, and in some purposes, changing current wired community infrastructure.

Measuring shipboard signal propagation for communication has been the point of interest of a number of studies [1]–[5]. Previous experiences excited about obtained power and route loss, as good because the effects of opening / closing doors (e.G.,[1]). The study in [4] measured the bought power measure, power delay professional file, and RMS delay spread of a wireless channel over multiple decks of a merchant ship. The measurements in [4] were used to estimate coherence bandwidth and delay spread, which can be used to calculate the highest rate at which narrow band communication methods can transmit information without experiencing inter symbol interference (ISI). Got power estimates had been additionally used to assess the influence of deploying a non wired relay in a carry shaft aboard the ship.

The studies performed in [6] used commercial off-the-shelf 802.11a/b radios to observe achievable throughput and latency. Orthogonal frequency-division multiplexing (OFDM) is suitable for this type of environment as a means to mitigate frequency selectivity that may reduce the role of coherence bandwidth as a limiting factor in wireless communications throughput. Multiple-input–multiple-output (MIMO) communications and multiple antenna techniques can also improve radio performance [7] by exploiting spatially uncorrelated fading of wireless channels common in multipath-rich environments to improve throughput and reliability.

The primary contribution of this letter is the quantification of the improvements in capacity, signal integrity, and throughput that can be observed through the use of OFDM and multi antenna techniques in below-deck environments.

This letter evaluates the performance of OFDM and MIMO technologies aboard Thomas S. Gates (CG 51), a decommissioned Ticonderoga-category US Navy cruiser. Shannon channel capacity and error-vector magnitude were directly measured through experimentation. Estimates of postprocessing signal-to-noise ratio (SNR) and achievable throughput are derived. These measures provide an estimate of the relative performance of physical layers over large scales, while illustrating how link-specific information can be used to improve network performance.

II. EXPERIMENTAL SETUP

A. Wireless System

Measurements were conducted using the Wireless Open Access Research Platform (WARP),a field - programmable gate array (FPGA)-Software program defined radio (SDR) test bed designed by way of Rice college of University, Houston, TX, united states of america, for prototyping of physic-layer and medium-access -control-layer algorithms [8]. The layers regarded on this letter were prototyped in the WARP Lab interface to WARP.

4 OFDM-established physical layers had been evaluated, particularly single-input and single-output (SISO), 1-2 maximal ratio combining (MRC), 2-2 MIMO Alamouti house-time coding, and a couple of 2 MIMO spatial multiplexing (MIMO-SM) utilising V-BLAST with an OFDM body constitution akin to that of 802.11g [9]. With the exception of transmission bandwidth, which is constrained by means of the SDR implementation, parameters are chosen in accordance with the 802.11a/g standard. A bandwidth of 10 MHz was divided into 64 sub carriers—four of which carry pilot symbols for clock drift and frequency offset correction, 12 are null to accommodate the provider, and the remainder forty eight sub carriers are loaded with knowledge-carrying symbols modulated using binary phase-shift keying (BPSK). At each measurement location, the designated transmitter broadcast 2400 packets at a center frequency of 2.484 GHz using every bodily layer. Man or woman packets consisted of a preamble for correlation-headquartered packet detection, 4 coaching symbols for channel estimation, and a payload of 10 OFDM symbols. For MIMO bodily layers, the total transmit vigour was divided evenly.

B. Performance Metrics

To evaluate the performance of each physical layer, an analysis of the channel capacity is provided. Estimation of Shannon capacity [9] illustrates the effects of changing channel conditions on throughput. The Shannon channel capacity is defined as the tightest upper bound on the amount Of information that can be transmitted over a communication Channel, in bps/Hz. It is the limiting rate at which data can be transmitted with arbitrarily small probability of bit error.
For a flat fading channel, the capacity is defined as

$$C = \log_2\left(1+\frac{P_{\mathrm{Tx}}|h|^2}{\mathcal{N}_0}\right) \qquad (1)$$

where P_{Tx} is transmit power, h is the complex channel gain, and N_0 is the noise power in the channel.

For an OFDM link with K subcarriers, there are K narrow-band flat fading channels. The channel capacity becomes the summation of the capacities of each subcarrier

$$C = \sum_{k=1}^{K} \log_2\left(1+\frac{P_{\mathrm{Tx},k}|h_k|^2}{\mathcal{N}_{0,k}}\right). \qquad (2)$$

This expression can be further expanded for MIMO as

$$C = \sum_{k=1}^{K} \log_2\left[\det\left(\mathbf{I}_{m\times n}+\frac{P_{\mathrm{Tx},k}}{m\mathcal{N}_{0,k}}\mathbf{H_k}\mathbf{H_k}^{\dagger}\right)\right] \qquad (3)$$

Where $\mathbf{H_k}$ is an $m \times n$ channel matrix with transmit antennas and n receive antennas. The entries $h_{i,j}$ represent the complex channel gain from Tx antenna to Rx antenna
To compare Shannon capacity fairly from experiments using separate physical layers, the channel gains are normalized such that $\|H\|_{\mathrm{Frobenius}} = mn$ [10].

PP-SNR has also been used as a metric to characterize channel quality.We define PP-SNR as the ratio of signal power to signal error, namely PP-SNR = $E[\|x\|^2 / \|\hat{x}-x\|^2]$. is similar to SNR, but sources of error affecting PP-SNR include nonlinear distortion in the radio transceiver, error in channel estimation, and noise enhancement from equalization. As a result, PP-SNR is a more hardware-specific description of SNR.

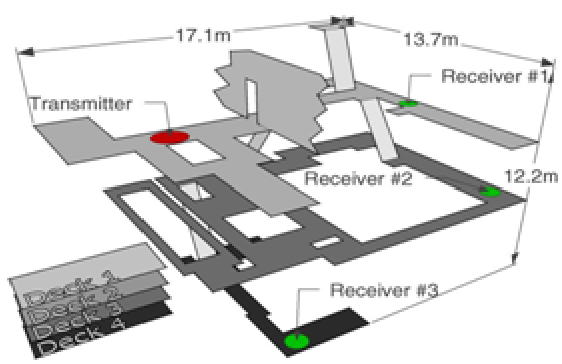

Fig. 1. Floor-plan sketch of the aft engine room. For clarity, machinery has been omitted.

Given a PP-SNR, the emblem error cost (SER) can also be estimated statistically from the receiver running attribute (ROC) curve of the rough choice bit decoder [11]. Conversely, for a given SER constraint, the maximum modulation order may also be calculated to estimate doable throughput.

III. MEASUREMENT SCENARIOS

Two portions have been chosen inside Thomas S. Gates to mannequin normal environments in a beneath-deck ship environment
.

1) Engine Room: Engine Room number 2 is a multi deck compartment towards the strict of the ship, housing one of the two major engines for ship propulsion. This compartment was once chosen as a place for checking out due to the fact that it is a contiguous house with generally metal development. Hence, signal scattering was once expected to be relatively excessive. In addition, this space was visible as a primary candidate for enforcing a wi-fi sensor community to monitor the fame of relevant ship machinery.

Fig. 1 shows the layout of the imperative decks in the primary engine room and the particular region of each radio node. Checks were performed within the engine room with nodes placed on three of the four decks over which the compartment spans. The void space between receivers 2 and three was occupied through the engine and exhaust stack, which spanned all decks. The radio locations were chosen to represent a combo of line-of sight and non-line-of-sight links and to reap an working out of coverage in a contiguous area spanning more than one decks.

2) Coupled Compartments: A cluster of spaces in an interior deck of the ship was used to research the coupling between adjoining and close-adjoining booths. A key purpose Used to be to check the outcome of closing watertight doors on signal integrity. Fig. 2 suggests the layout of these coupled booths as well as the areas of the nodes used within the experiment. The transmitter node used to be located in compartment A, and the 2 receiver nodes had been located in compartments B and C. Compartment A entails an emergency get away scuttle into compartment C (this scuttle used to be closed at some stage in the trying out), and an exhaust duct with vents connects compartments A and B. Even as the doorways and hatches are watertight, there exist ventilation ducts, piping, and different protrusions that create an potent aperture for lectromagnetic signals to propagate between the compartments.

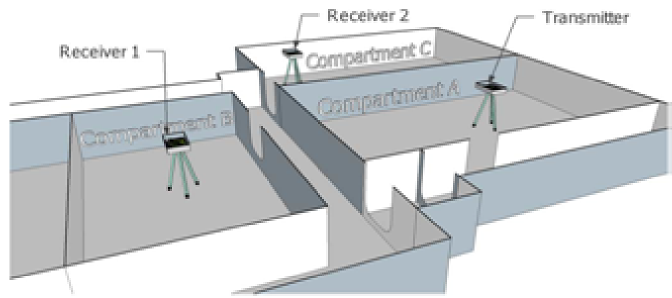

Fig. 2. Floor plan of the adjacent compartments used for the coupled compartment measurements.

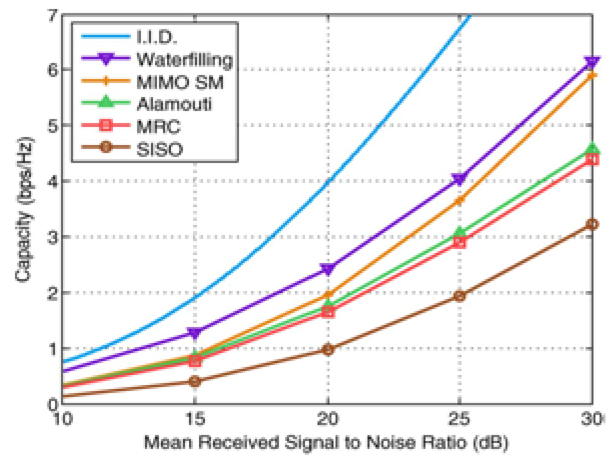

Fig. 3. Capacity for each physical layer averaged across all channels between the transmitter and each receiver in the engine room.

TABLE I
PP-SNR FOR EACH PHYSICAL LAYER MEASURED AT EACH RECEIVER LOCATION IN THE ENGINE ROOM

Rx Location	SISO	1x2 MRC	Alamouti	MIMO-SM
1	21.4	23.1	22.8	16.8
2	11.5	17.6	18.5	11.6
3	10.4	13.9	14.6	7.4

IV. EXPERIMENTAL RESULTS

A. Engine Room

common capacities for the various physical layers used in the engine room are proven as a operate of usual SNR in Fig. 3. The capacity is averaged over all receivers for every sort of physical layer demonstrated. The water-filling solution represents the upper bound of capability for the link [9], [12], whilst independent, identically allotted (i.I.D.) channels signify the best possible theoretical achieve conceivable in any MIMO link of equal channel norm. Considering that the channels are normalized with appreciate to achieve per receiver, the result of spatial correlation is isolated in the MIMO channel on Shannon capability as shown in [10]. As verified in Fig. Three and table I, the channel is spatially decorrelated ample to aid the use of MIMO approaches to enhance performance over SISO tactics. The capability is roughly doubled by using MIMO-SM over SISO.

PP-SNR for each physical layer and receiver location is proven in desk I. Hyperlink 1, being the shortest link and

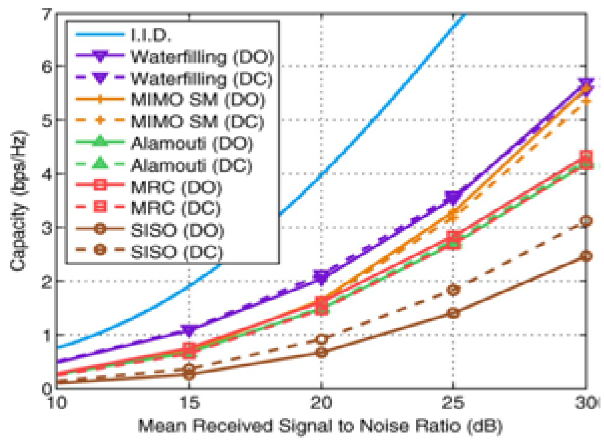

Fig. 4. Capacity for the channel between the Transmitter and Receiver 1 (compartment B) in coupled compartments for both open (DO) and closed (DC) door scenarios and all physical layers.

nearest to Line-of-sight, has the perfect PP - SNR. In most situations, the PP-SNR is highest for Alamouti coding. This outcome is predicted due to introduced range attain from house-time coding, with similar performance from MRC, one other variety scheme. Even as MIMO-SM has the bottom PP-SNR, it is transmitting at twice the info price of different schemes.

B. Coupled Compartments

The measurements in the coupled compartments show two specific behaviors emerging from variations in physical layout. As proven in Fig. 2, the Transmitter is separated from Receiver 1 by using two bulkheads and a hallway. The foremost pathway for the sign is through this hallway when the doors are open, nevertheless it must propagate by means of apertures within the bulkheads (such as the ventilation ducts) when they're closed. Nevertheless, the Transmitter is separated from Receiver 2 through a single bulkhead.When the doorways are open, there's a single lengthy pathway for the signal to propagate to the receiver via the hallway.

The capacity for the channel between the Transmitter and Receiver 1 (Fig. 4) improves for SISO when the doorways are closed. For the reason that the trail loss from the channel is normalized, this development shows the channel has a flatter response (less frequency selectivity). That is regular with a lessen in multipath alerts arriving at Receiver 1 and an broaden within the dominance of the signals arriving through ductwork connecting the two areas. Given that MIMO systems mitigate frequency selectivity via antenna range, the negligible exchange within the capacity of these schemes would point out that the channel correlation (a predominant factor in potential) does now not trade in a tremendous manner when the doorways are opened or closed.

The capability for the channel between the Transmitter and Receiver 2 (Fig. 5) improves for both SISO and MIMO schemes when the doors are closed. The advance for SISO suggests that frequency selectivity decreases, much like the outcomes seen at Receiver 1. The development for MIMO suggests that the channel correlation also decreases, unlike the outcomes obvious at Receiver 1.

The PP-SNR of each receivers is proven in table II for open and closed doorways. The sign integrity decreases for Receiver 1

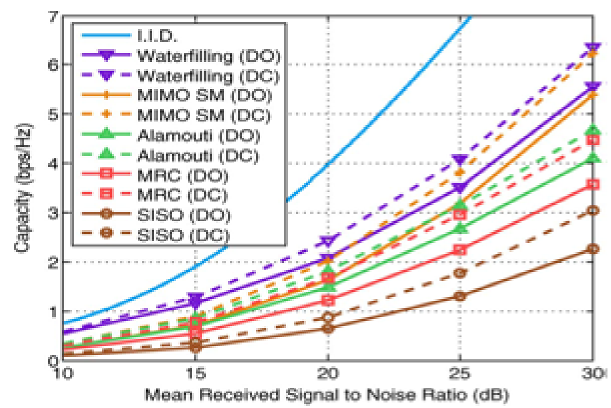

Fig. 5. Capacity for the channel between the Transmitter and Receiver 2 (compartment C) in coupled compartments for both open (DO) and closed (DC) door scenarios and all physical layers.

TABLE II
PP-SNR FOR EACH PHYSICAL LAYER IN THE COUPLED COMPARTMENT EXPERIMENT FOR DOORS OPEN (DO) AND DOORS CLOSED (DC)

RX Location	SISO		1x2 MRC		Alamouti		MIMO-SM	
	DO	DC	DO	DC	DO	DC	DO	DC
1	11.4	11.0	21.5	15.3	18.5	15.0	14.2	8.6
2	15.0	21.1	19.8	22.3	18.2	19.8	12.6	15.5

(DO) = doors opened, (DC) = doors closed

TABLE III
ACHIEVABLE THROUGHPUT (Mb/s)

Scenario	SISO		MRC		Alamouti		MIMO-SM	
	Min	Max	Min	Max	Min	Max	Min	Max
Engine Room	6	18	12	18	12	18	12	36
Coupling (DO)	12	12	18	18	18	18	24	24
Coupling (DC)	12	18	12	18	12	18	12	24

(DO) = doors opened, (DC) = doors closed

When the doors are closed. Regardless of the cut down in frequency selectivity, the attenuation of the signal when the doors are closed still outcome in an overall lessen in integrity. PP-SNR raises for Receiver 2 when the doors are closed, steady with the dominant sign element coming by way of apertures within the bulkhead and the multipath sign from the hallway deconstructively interfering when the doorways are open.

C. Achievable Throughput

The manageable throughput on every hyperlink used to be calculated via selecting the best viable base-2 modulation order (BPSK, 4-QAM, 16-QAM, or sixty four-QAM) for the measured PP-SNR values from Tables I and II with an SER constraint of 1 in 10 [11]. Each the minimum and highest possible throughput for each and every scenario are shown in desk III.

For the poorest-exceptional links, SISO used to be handiest capable to receive a throughput of 6 Mb/s within the engine room and 12 Mb/s for the coupled compartments. MIMO systems had been ready to double the throughput of SISO for the engine room and coupled compartments (with doors open). Even as now not fairly as high because the aforementioned situations, improvement was nonetheless realized in the coupled booths with the doors closed as well. At maximum, MIMO-SM throughput reached 36 Mb/s.

V. CONCLUSION

Measurements aboard Thomas S. Gates furnish proof that Multi antenna technologies can make stronger communications performance over SISO strategies in a under-deck environment. MIMO technologies offer improved ability and less variation in procedure efficiency regardless of changing environmental causes.

The PP-SNR values presented exhibit the advance in reliability that may be furnished by means of area-time coding. Estimation of Shannon channel capacity demonstrates that multipath scattering may also be exploited with the aid of spatial multiplexing to toughen performance and increase throughput.

The plausible throughput was once as high as 36 Mb/s despite the reverberant conditions limiting the coherence bandwidth. On the poorest-quality hyperlink, SISO communications were restrained to 6 Mb/s within the engine room, whilst MIMO physocal layers had been able to function at 12 Mb/s, thereby doubling the link throughput. Similar performance good points were discovered in the coupled compartments with doorways open.

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