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Smart Antennas for Communications in Line of Sight

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ABSTRACT: Throughout the world, including the United States, there is significant research and development on smart antennas for wireless systems. This is because smart antennas have tremendous potential to enhance the performance of future generation wireless systems as evidenced by the antennas' recent deployment in many systems. It covers smart antenna technology, including software and system aspects. First the two basic types of smart antennas, adaptive and phased arrays are described and then their current use and proposed use in future wireless systems is discussed. A smart antenna is therefore a phased or adaptive array that adjusts to the environment. That is, for the adaptive array, the beam pattern changes as the desired user and the interference move; and for the phased array the beam is steered or different beams are selected as the desired user moves. We describe and analyze adaptive antenna array technology to improve naval communications systems to beyond line-of-sight at microwave frequencies by using the ducting layer as a leaky waveguide and the adaptive array to resolve and coherently combine multipath in this layer.

KEYWORDS: Adaptive, Array, Naval, HF , Ducting

1 .INTRODUCTION

Future wireless systems generally may require higher data rates with better coverage for a wide variety of users operating with a large variety of different systems. To achieve these goals, greater power, interference suppression, and multipath mitigation are needed. As users operate at higher data rates, they need higher power for adequate reliability. For higher bandwidths, higher carrier frequencies that have higher propagation and circuit losses are needed. So some way to recover this power must be developed. In addition, interference suppression is needed for higher capacities. Particularly as higher frequency reuse is used to increase capacity, there will be more .Co-channel interference, which requires greater interference suppression. Finally, multipath mitigation to have more reliable and robust communications is necessary. We can provide a communications link between naval assets using a ship-based communications suite using adaptive array antennas under various fading and shadowing conditions. The ability to provide line-of-sight (using the 4/3 earth model) is limited to relays (airborne platforms) located at higher altitudes for these extended ranges; during operations and under hostile conditions this high altitude requirement may be prohibitive (see Figure 1). Aerosols cause high losses in the ducting layer; however, the ducting layer can be considered a leaky waveguide, lossy due to the absorptive effects of the sea surface and penetration of the duct by the EM field.

Even with these losses, a marine boundary ducting layer acting as a waveguide propagation advantages over isotropic propagation. Since the ducting layer is a disk that confines the signal to the volume of a disk, the spreading loss for the duct-confined propagation path is linearly proportional to the range, versus at least the range squared for line of line-of-sight propagation. For specific conditions, the use of ducting can provide as much as a 40 dB stronger signal at 1000 km. However, the ducting layer also creates multipath, since the duct acts as a leaky waveguide, with the signal reflecting or being absorbed into the sea surface (the bottom of the duct) and the ill-defined duct transition. Additionally, intersymbol interference (ISI) due to the arrival of separate copies arriving will degrade the signal; one or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit.

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II. ADAPTIVE ANTENNA ANALYSIS

Smart antennas can help systems meet these requirements in the following manner: First, both phased and adaptive arrays provide increased power by providing higher gain for the desired signal. Phased arrays use narrow pencil beams, particularly with a large number of antenna elements at higher frequencies, to provide higher gain (power) in the direction of the desired signal. Adaptive arrays place a main beam in the direction of the desired signal for an M-fold power gain with M antenna elements. In terms of interference suppression, phased arrays reduce the probability of interference with the narrower beam, and adaptive arrays adjust the beam pattern to suppress interference. For multipath mitigation, smart antennas can provide diversity, of which there are three basic types: spatial, polarization, and angle (or pattern) diversity.

Adaptive antennas can mitigate these effects, employing proven techniques, such as maximal ratio combining (MRC) or optimum combining. The multipath channel is estimated at the receive antenna array to determine the best pattern to combine the diversity branches, and the adaptive array uses the same pattern on transmit as receive (assuming the same frequency) — thus learning can be done on receive only. Using smart antenna techniques to combine the various multipath elements coherently allows for effective communications, providing array and diversity gain, as well as interference suppression.

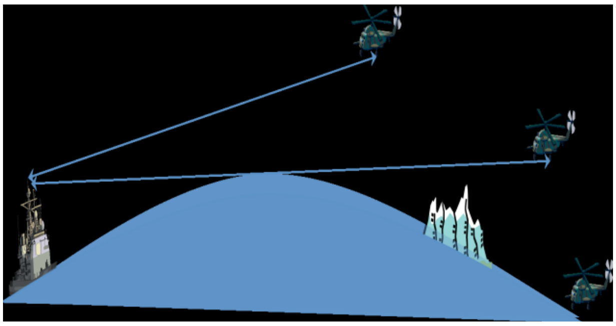

Figure 1. Natural phenomena to provide ubiquitous high capacity beyond line-of-sight communications

III. LINE-OF-SIGHT COMMUNICATION METHOD

Communication links between naval assets can be improved using an expanded ship-based communications suite under various environmental, fading, and shadowing conditions. For most operational conditions, line-of-sight communication requires relays (airborne platforms, such as the LAMPS helicopter) located at higher altitudes to achieve these required extended ranges; however, during tactical operations and under hostile conditions, this high altitude requirement may be prohibitive. For example, since the primary LAMPS missions are to support surface warfare (SUW) and Undersea Warfare (USW) during which the LAMPS helicopter operates at low altitude, requirements to rise above the horizon to transfer data expose the crew and craft to possible hostile action and consume valuable mission time. Current antenna systems do not take advantage of multipath and delay spread.The current line-of-sight communication method is subject to higher probability of detect/ intercept. Given the multitude of antennas and RF systems competing for ever scarcer physical and spectral real estate on modern aircraft fuselages and ship superstructures, both multipath from the structures and unintentional jamming from adjacent channels or platforms present greater interference challenges over the intentional adversarial jamming our military systems must detect and mitigate.

As an alternative to line-of-sight communications using relays, over-the-horizon communications capabilities at high frequency (HF), but the limited spectrum and bandwidth at these frequencies preclude HF solutions for many applications and thus motivate new techniques. The need to exchange high bandwidth data emerges as cooperative networked radar and electronic warfare uses legacy systems against emerging threats. The multitude of RF antennas on the mast of naval platforms causes spectral and physical crowding problems, the mechanical wear of rotating dish equipment, poor performance due to the blockage of these antennas, and size, weight and power (SWAP) considerations. Phased array also can be employed for naval communications corresponding plot.

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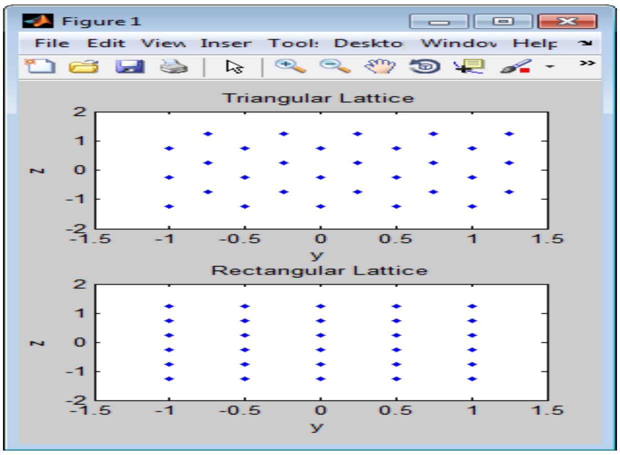

Figure 2 : Practical phased array antenna

IV. EXTENSION OF ADAPTIVE ANTENNA USING MIMO

The propose to use adaptive antenna array technology to extend naval communications systems beyond line-of-sight at microwave frequencies using the ducting layer as a leaky waveguide. Our new techniques allowing low elevation communications at long distances increase both mission safety and effectiveness. When the system capacity is unavailable, natural phenomena will provide a reliable and high throughput alternative. Adaptive arrays allow the resolution and coherently combining of multipath signals in the ducting layer while supporting related multiple input- multiple-output (MIMO) communications techniques. While relays and ducting methods may be limited by the current environmental conditions, these enhanced channels, in combination with ad hoc networking, can maintain high data rate communications even with a low probability of detect/intercept. The traditional view of the duct being lossy and degraded by multipath and delay spread is reversed by the new adaptive array, MIMO, and orthogonal frequency division multiplexing (OFDM) capabilities which provide additional benefits *because* of these effects. Recognizing the Navy's current investment and development efforts, our proposed implementation can leverage off a shared aperture using an appliqué approach.

To analyze and demonstrate the feasibility of beyond line-of-sight communications using the ducting layer with adaptive arrays to provide multipath mitigation and MIMO communications, as well as using a shared aperture, appliqué, and ad hoc networking. The probability distribution of the communication data rates supported by these channels, and note the reduction in signal probability of detect/ intercept. Specifically, adaptive antennas, MIMO (multiple channels in the same bandwidth), and OFDM waveforms turn impairments into facilitators.
1 .Adaptive antennas to mitigate multipath fading and provide MIMO capabilities.
2. Ad hoc networking to provide reliable communications at the highest possible data rates using a variety of channels, some of which are unreliable, such as the ducting layer.
3. Shared apertures with appliqués to minimize changes to existing systems.

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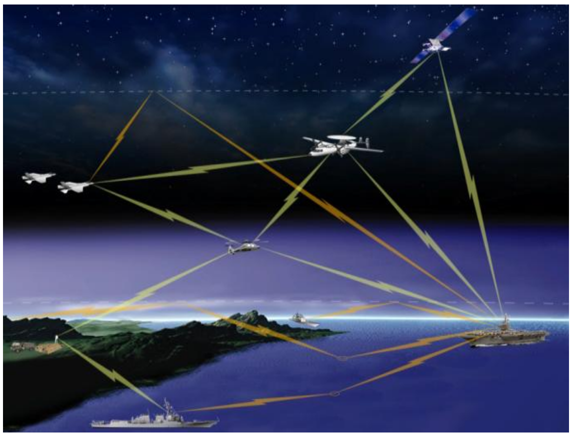

Figure3. Adaptive arrays offer ducting layer channels to provide enhanced Naval Communications.

Adaptive antennas can mitigate multipath fading effects and suppress interference by employing proven techniques such as maximal ratio or optimum combining. With these techniques, the multipath channel is estimated at the receive antenna array and the best pattern is determined by combining the multiple antennas. Assuming the same transmit and receive frequency, the adaptive array uses the same pattern information on transmit allowing all learning to be done on receive only.

Adaptive array techniques combine the various multipath elements coherently to allow for effective communication, providing array and diversity gain, as well as interference suppression. Using diversity with adaptation to establish communications, the mission can be achieved with higher data rates and fewer communications outages than would typically occur at long distances and low altitudes. With multipath, MIMO techniques can increase the data rate *M*-fold with *M* transmit/receive antennas. MIMO also decreases probability of detect/intercept, since an eavesdropper with less than *M* antennas and channel knowledge will see a multitude of noise like/faded, interfering signals. With adaptation, MIMO versus gain can be traded off as conditions vary, for example by using diagonal loading techniques.

Ad hoc networking uses a variety of channels to provide reliable communications. A marine boundary-ducting layer acting as a waveguide has some propagation advantages over isotropic propagation. While losses in the ducting layer are high due to aerosols, the ducting layer can be used as a leaky waveguide (lossy due to the absorptive effects of the sea surface and penetration of the duct by the electromagnetic field). The ducting layer creates multipath with the signal reflecting or being absorbed into the sea surface (the bottom of the duct) and the duct transition. This leaky waveguide will create several eigen modes due to the uneven nature of the top of the ducting layer.

Multiple copies of a signal will arrive through the leaky waveguide at different phases, as the different copies have traversed different path lengths. If the phases of these different copies add destructively, the signal level relative to noise declines, making detection more difficult. Additionally, intersymbol interference (ISI) due to the arrival of separate copies will degrade the signal: one or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit. Studies of the ducting layer have measured this delay spread in the ducting layer, as well as the distribution of the losses over time. Since the ducting layer confines the signal to the volume of a disk, the spreading loss for the duct confined propagation path is linearly proportional to the range, versus at least a range squared loss for line-of-sight propagation. The loss due to aerosols in the ducting layer is compensated by the lower propagation loss due to the smaller spreading volume of the duct versus the isotropic case. For specific conditions, the use of ducting can provide as much as a 40 dB stronger signal at 1000 km. Although ducting does not provide a highly reliable communication channel, ad hoc networking techniques can sustain reliable high data rate communications even though the ducts between

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V.PERFORMANCE ANALYSIS

Although analysis of the performance of these techniques requires further refinement and development of the respective channel models, we have performed preliminary performance analysis. To illustrate this improvement, we simulated using MATLAB a link using 274 Mb/s offset QPSK (OQPSK). This link used a concatenated coding scheme: an inner convolutional coding with an outer reed- Solomon encoding. The results show that the adaptive array can provide communications with a 20 dB improvement for two-branch diversity combining and a 27 dB gain using three-branch diversity combining. In addition, MIMO arrays can provide high capacity communication between surface vessels and suitably equipped airborne vessels. Further low cost approaches to multipath and interference mitigation include designing the current system as an appliqué, with a final evolution of approach using COTS SDR solutions that have RF interfaces that allow for multi-branch-diversity combining. Thus, using diversity with adaptation to establish communications in the ducting layer, a mission can operate with fewer communications outage.

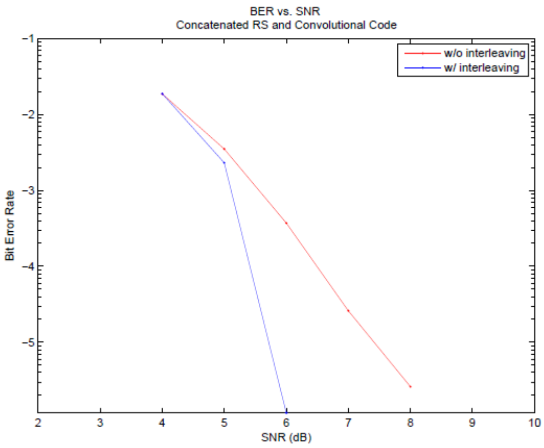

Figure 4:BER Vs SNR

VI.FUTURESCOPE

I have completed initial research on each individual solution. However, additional work is needed to fill in the required additional pieces and integrate them to demonstrate feasibility.

1. Analyze the ducting channel to develop models and determine the angular spread (which has not been previously studied),delay spread, and multipath. Angular spread is the range of angles over which the signal is received and determines the antenna spacing for the required diversity with adaptive antennas. This angular spread will be measured in both azimuth and elevation. Wireless In site software is one means to simulate the channel information.
2. Measure ducting channels to verify the models of part 1.
3. Use this analysis and measurements with well-known adaptive array techniques, as well as ad hoc networking techniques, to analyze the ability of our approach to provide high data rate, highly reliable beyond line-of-sight communications. The effect of interference and the reduction in probability of detect/intercept also should be analyzed.
4. Evaluate practical implementation techniques for shared aperture/appliqués. The Integrated Topside (In Top) concept can provide a basis to develop and demonstrate an integrated, multi-function, multi-beam top-side aperture construct that meets our goals with shared array apertures.
5. This technology can be demonstrated using developed channel models with computer simulation of the techniques verified with measured channel data .Our technical approach uses a combination of well-known and tested techniques, including adaptive arrays, MIMO, and ad hoc networking ,in a novel way that has not been previously considered for well-known propagation media,such as ducting channels. These techniques use multipath and fading, which were previously considered impairments, to enhance communications. Additional measurements are needed to determine the

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channel parameters relevant for these techniques. There is high potential payoff of such high data rate, highly reliable, beyond line-of-sight communications to both operational mission safety and success. Further low cost approaches to multipath and interference mitigation include designing the current system as an appliqué, with a final evolution of approach using COTS .SoftwareDefined Radio (SDR) solutions that have RF interfaces that allow for multi-branch-diversity combining. Thus, using diversity with adaptation to establish communications in the ducting layer, a mission can operate with fewer communications outages.

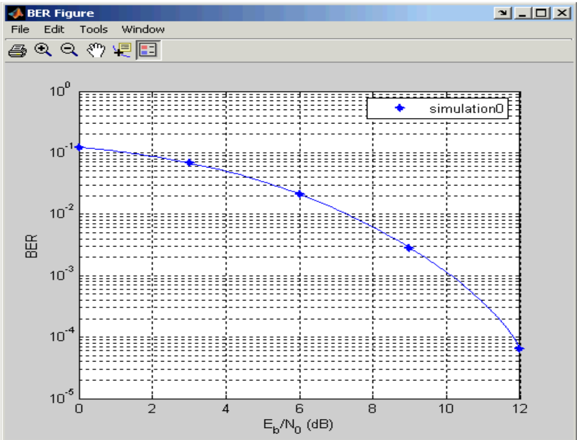
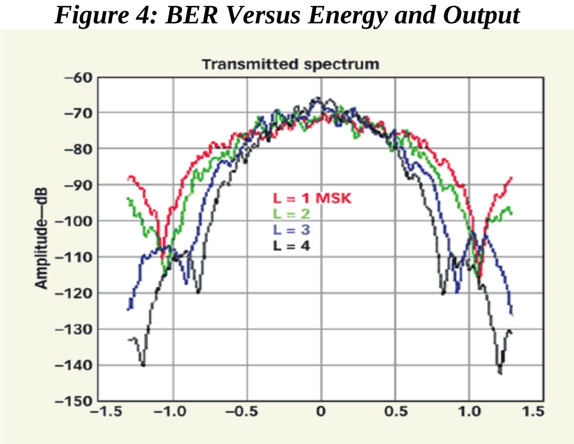


Figure 4: BER Versus Energy and Output



9. This CPM spectrum plots signals based on different values of L.

Figure 5:OQPSK Performance

VII. CONCLUSIONS

I have proposed the use of the ducting layer, with adaptive antennas, MIMO, ad hoc networking, appliqués, and shared apertures, to improve naval communications systems to beyond line-of-sight at microwave frequencies..By using the ducting layer as a leaky waveguide and the adaptive array to resolve and coherently combine multipath in this layer, we are exploiting natural phenomena that were previously considered impairments to enhance performance using sophisticated signal processing. Our preliminary results show significant gain can be achieved.

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